E M C / E M I DESIGN SEMINAR

Helping Designers Understand and Avoid EMI Problems in Hardware Design.

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Electromagnetic Environment
EMC Regulations
Design With EMI in Mind versus Patching Bad Designs
Sources of EMI Noise
EMI Propagation Paths
Radiation From Printed Circuits, Proper Design & Layout
Ways to Minimize EMI, Signal Conditioning & Filtering

Coupling and Decoupling on Wires, PC Traces & Cables
Why Shielded Cables Sometimes Do Not Shield
Common Impedance Coupling
Coupling: Common Mode, Ground Loops, Differential Mode
Decoupling Using Twisted Wire Pairs & Shields
EMC Filters and Designing Simple Filters

Understanding Shielding and Materials
Reduction of EMI From and To Enclosures
Primer on EMC/EMI Testing
Outdoor Test Site vs Shielded Rooms
Lab Bench Testing
Equipments, Receivers and Spectrum Analyzers
Antennas & Probes (How to Build One)
Sources For EMC/EMI Training & Publications

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Proposed schedule: 0840-1010, (break), 1030-1200, (lunch), 1300-1400.
(Optional: Add 1 hour of discussion, if you wish.)

This is a one day (or two day) marketing version. It will be brief, covering about 1/3 of the material of a regular HP EMI engineering seminar.

HP Hong Kong/ Singapore
EMI-1day / Dec 1987
Tentative

EMISSION CONTROL

IN

ELECTRONIC EQUIPMENT

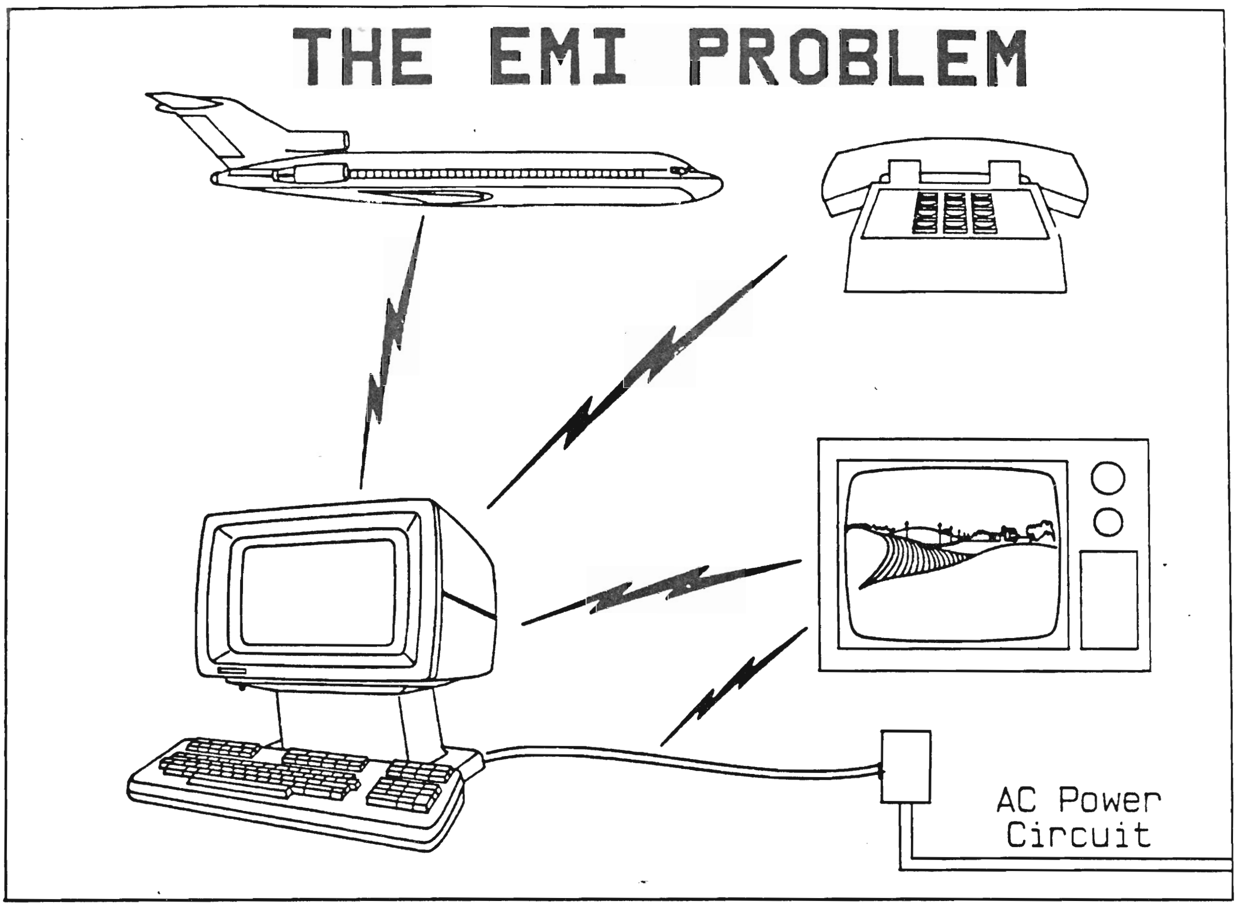
DESIGNING FOR EMC

INTERNAL PROBLEMS

SUSCEPTIBILITY FROM OUTSIDE SOURCES

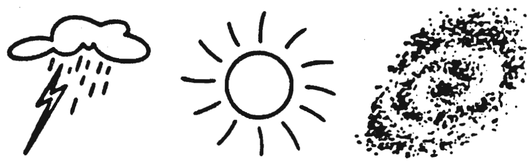
EMISSION TO THE ENVIRONMENT

1. CONTROL EMISSIONS FROM EQUIPMENT
2. CONTROL EMISSIONS FROM INTERCONNECTING CABLES



SOURCES OF EMI

Natural



Man-Made

Intentional

Unintentional

TERMS AND DEFINITIONS

EMC
(ELECTROMAGNETIC COMPATIBILITY)

THE ABILITY OF A DEVICE/SYSTEM TO OPERATE NORMALLY, YET CAUSE NO DEVIATIONS IN THE NORMAL OPERATION OF OTHER DEVICES/SYSTEMS IN ITS INTENDED ELECTROMAGNETIC SURROUNDINGS

TERMS AND DEFINITIONS

EMI
(ELECTROMAGNETIC INTERFERENCE)

THE DISRUPTION OF NORMAL OPERATION OF A DEVICE/SYSTEM (VICTIM) CAUSED BY THE PRESENCE OF UNDESIRABLE OR UNINTENDED ELECTROMAGNETIC ENERGIES EMANATING FROM ANOTHER DEVICE/SYSTEM (SOURCE)

RFI
(RADIO FREQUENCY INTERFERENCE)

THE FORMERLY-USED TERM FOR EMI

TERMS AND DEFINITIONS

AMBIENT	=	SURROUNDINGS AROUND EQUIPMENT
E FIELD	=	ELECTRIC FIELD, VOLTS/METER, MICRO V/m
H FIELD	=	MAGNETIC FIELD, TESLA (10^4 GAUSS), MICRO A/m
FAR FIELD	=	$>30\lambda$ (30 WAVELENGTHS)
NEAR FIELD	=	$<30\lambda$

TERMS AND DEFINITIONS

FREQUENCY BANDS

		SUB AUDIO	=	LESS THAN 10 HERTZ
		AUDIO	=	10 TO 20,000 Hz
ELF	=	EXTREMELY LOW FREQUENCY	=	30 TO 300 Hz
VF	=	VOICE FREQUENCY	=	300 TO 3000 Hz
VLF	=	VERY-LOW FREQUENCY	=	3 TO 30 KILOHERTZ
LF	=	LOW FREQUENCY	=	30 TO 300 KHz
MF	=	MEDIUM FREQUENCY	=	300 TO 3000 KHz
HF	=	HIGH FREQUENCY	=	3 TO 30 MEGAHERTZ
VHF	=	VERY-HIGH FREQUENCY	=	30 TO 300 MHz
UHF	=	ULTRA-HIGH FREQUENCY	=	300 TO 3000 MHz
SHF	=	SUPER-HIGH FREQUENCY	=	3 TO 30 GIGAHERTZ
EHF	=	EXTREMELY HIGH FREQUENCY	=	30 TO 300 GHz
MW	=	MICROWAVES	=	1 GHz TO 30 GHz
MMW	=	MILLIMETER WAVES	=	30 TO 300 GHz

TERMS AND DEFINITIONS

dB = DECIBEL
10 dB = POWER RATIO OF 10 = VOLTAGE RATIO OF 3.16
20 dB = POWER RATIO OF 100 = VOLTAGE RATIO OF 10.0
dBW = dB REFERENCED TO ONE WATT
dBm = dB REFERENCED TO ONE MILLIWATT
dBμV/m = dB REFERENCED TO ONE MICROVOLT PER METER
dBμA/m = dB REFERENCED TO ONE MICROAMP PER METER

TYPICAL EMC/EMI REGULATIONS

DIVIDED INTO:

EMISSION (OUTPUT)	SUSCEPTIBILITY (INPUT)
ABILITY OF SUBJECT UNIT TO PREVENT OUTPUT OF UNINTENDED ELECTROMAGNETIC ENERGIES	ABILITY OF SUBJECT UNIT TO OPERATE PROPERLY IN THE PRESENCE OF SPECIFIED LEVELS OF BACKGROUND ELECTROMAGNETIC ENERGIES

DB..... DBμV..... DBμA..... DBW..... DBM

$\#DB = 10 \; Log_{10} (P_1 / P_0)$ $\#DB = 20 \; Log_{10} (V_1 / V_0)$ OR (I_1 / I_0)

DB	POWER RATIO	VOLTAGE OR CURRENT RATIO	DB	POWER RATIO	VOLTAGE OR CURRENT RATIO
0	1.0	1.0	10	10	3.16
1	1.26	1.12	20	100	10.0
2	1.59	1.26	30	1000	31.6
3	2.0	1.41	40	10000	100
4	2.51	1.58	50	10^5	316
5	3.16	1.79	60	10^6	1000
6	4.0	2.0	70	10^7	3162
7	5.01	2.24	80	10^8	10000
8	6.3	2.51	90	10^9	31623
9	7.94	2.82	100	10^{10}	100000

DB..... DBμV..... DBμA..... DBW..... DBM

$\#DB = 10 \; Log_{10} (P_1 / P_0)$ $\#DB = 20 \; Log_{10} (V_1 / V_0)$ OR (I_1 / I_0)

DB	POWER RATIO	VOLTAGE OR CURRENT RATIO	DB	POWER RATIO	VOLTAGE OR CURRENT RATIO
0	1.0	1.0	-10	.1	.316
-1	.79	.89	-20	.01	.10
-2	.63	.80	-30	.001	.0316
-3	.50	.71	-40	.0001	.01
-4	.40	.63	-50	10^{-5}	.00316
-5	.316	.56	-60	10^{-6}	.001
-6	.25	.50	-70	10^{-7}	.000316
-7	.20	.45	-80	10^{-8}	.0001
-8	.16	.40	-90	10^{-9}	.0000316
-9	.13	.35	-100	10^{-10}	.00001

4/85 DB1

TYPICAL EMC/EMI REGULATIONS

EMISSIONS

CONDUCTED

POWER LEADS
CONTROL LEADS
- IEEE 488
- RS232B

SIGNAL LEADS
- ANALOG INPUT/OUTPUT

ANTENNA TERMINALS

[CARRIED BY WIRES CONNECTED TO THE SUBJECT UNIT]

RADIATED

MAGNETIC FIELD
ELECTRIC FIELD

[ELECTROMAGNETIC FIELDS RADIATED DIRECTLY FROM THE SUBJECT UNIT]

WHO MAKES THE RULES?

COMMERCIAL

• FCC	USA
• FTZ/VDE	Germany
• DOC	Canada
etc.	

MILITARY

- MIL-STD 461,462

REGULATIONS/STANDARDS

FCC - PART 15, SUBPART J: COMPUTING DEVICES
(TIMING PULSES >10KHz)

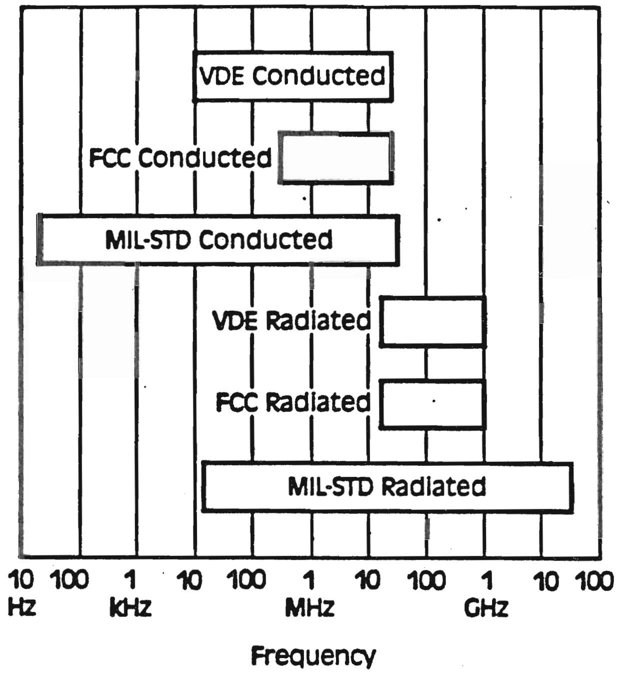
FTZ - 526, 527: PERMIT FOR MEASUREMENT RECEIVERS
- 1046/1984: GENERAL LICENSE FOR RF EQUIPMENT

VDE - 0871: EMI LIMITS FOR HIGH FREQUENCY
- 0875: EMI LIMITS FOR LOW FREQUENCY

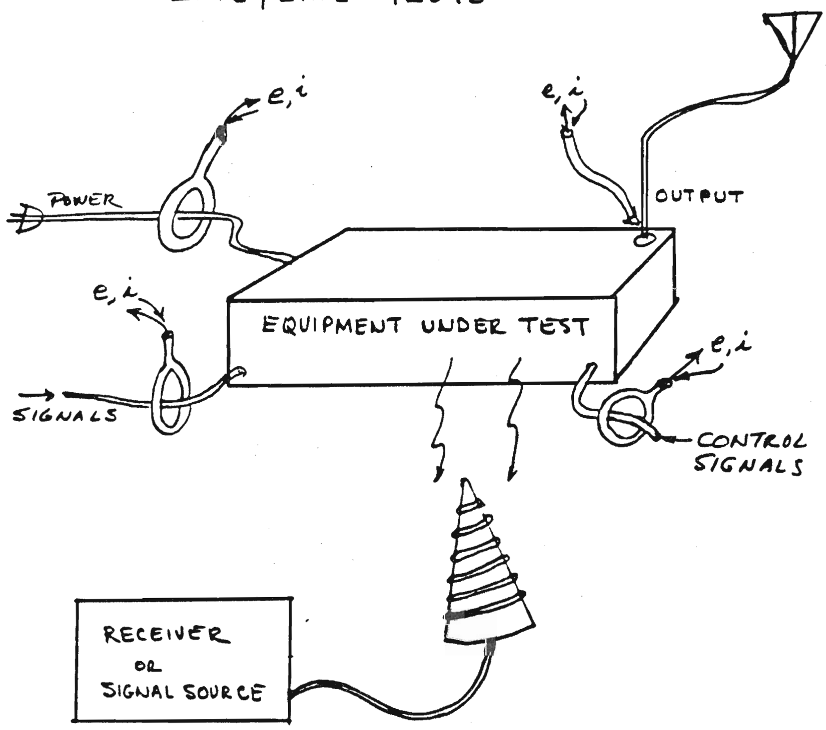
CISPR - 11: STANDARDS FOR EMI LIMITS

CISPR - 22: EMI LIMITS/MEASUREMENTS FOR INFORMATION TECHNOLOGY EQUIPMENT

THERE ARE MANY EMC REGULATIONS COVERING A WIDE RANGE OF FREQUENCIES

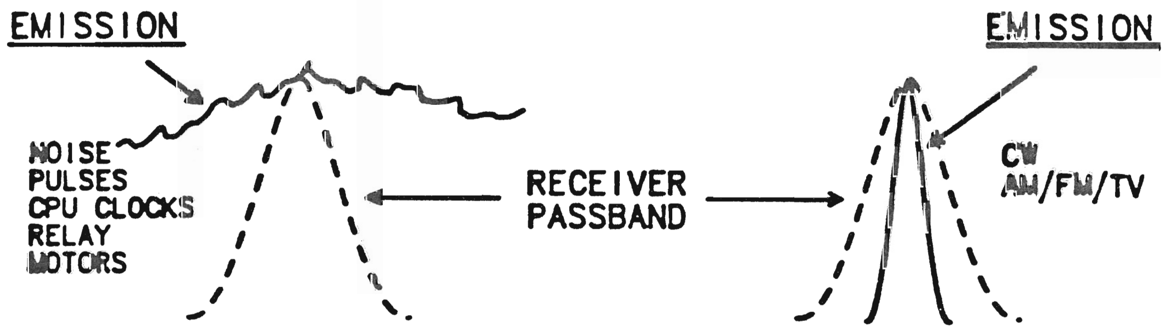


EMC / EMI TESTS



TYPICAL EMC/EMI REGULATIONS

EMISSIONS ARE CLASSIFIED AS BROADBAND OR NARROWBAND



BROADBAND NARROWBAND

TYPICAL EMC/EMI REGULATIONS

SUSCEPTIBILITY

CONDUCTED

POWER LEADS
- ABSORPTION OF EM ENERGIES
  - SWITCHING OR OTHER TRANSIENTS (SPIKES)

CONTROL & SIGNAL LEADS
- ABSORPTION OF EM ENERGIES

ANTENNA TERMINALS
- INPUT OF UNDESIRED SIGNALS ALONG WITH DESIRED SIGNAL

[UNDESIRED EM ENERGIES ENTERING SUBJECT UNIT VIA WIRES]

RADIATED

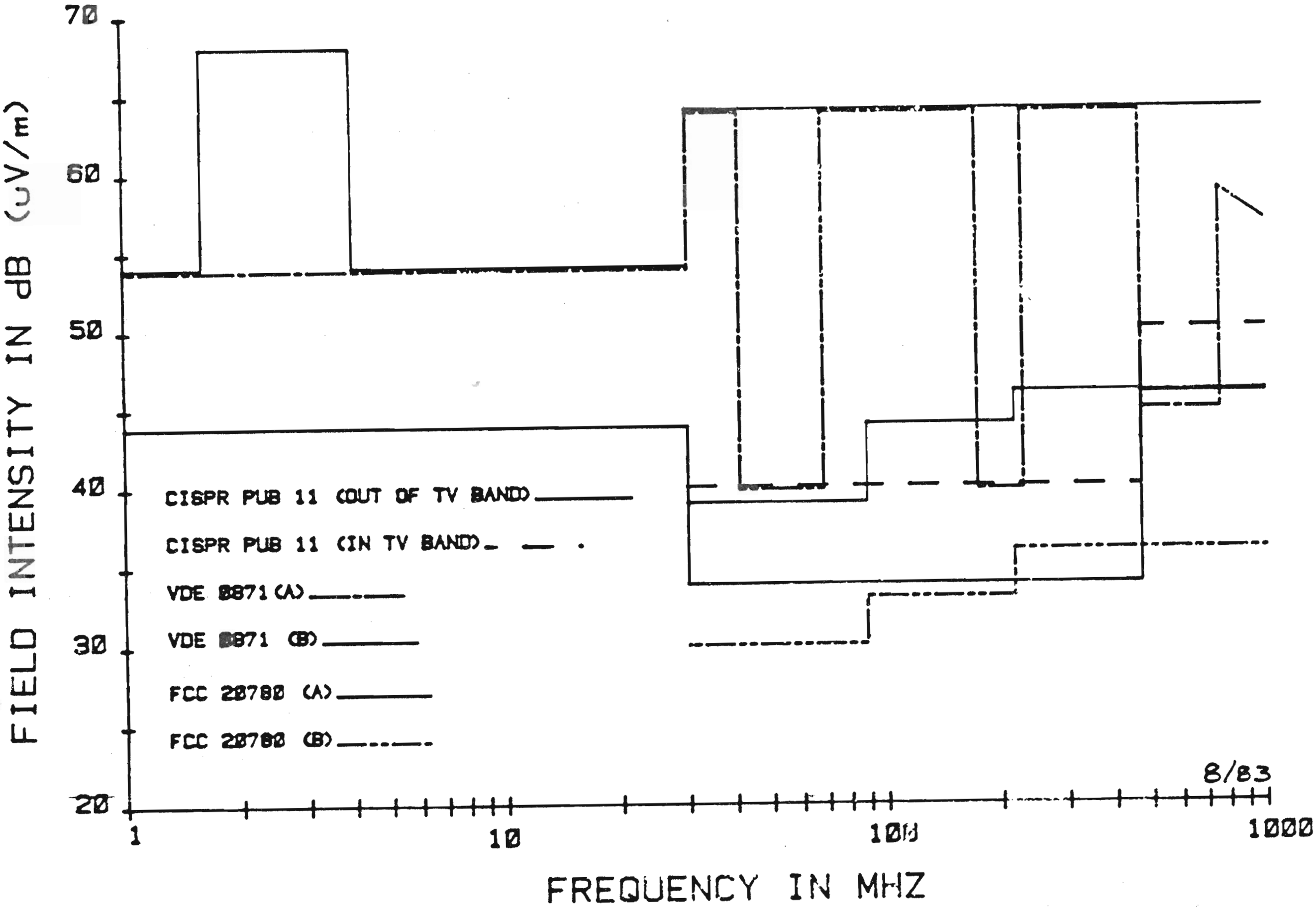
MAGNETIC FIELDS
- MOTORS, TRANSFORMERS

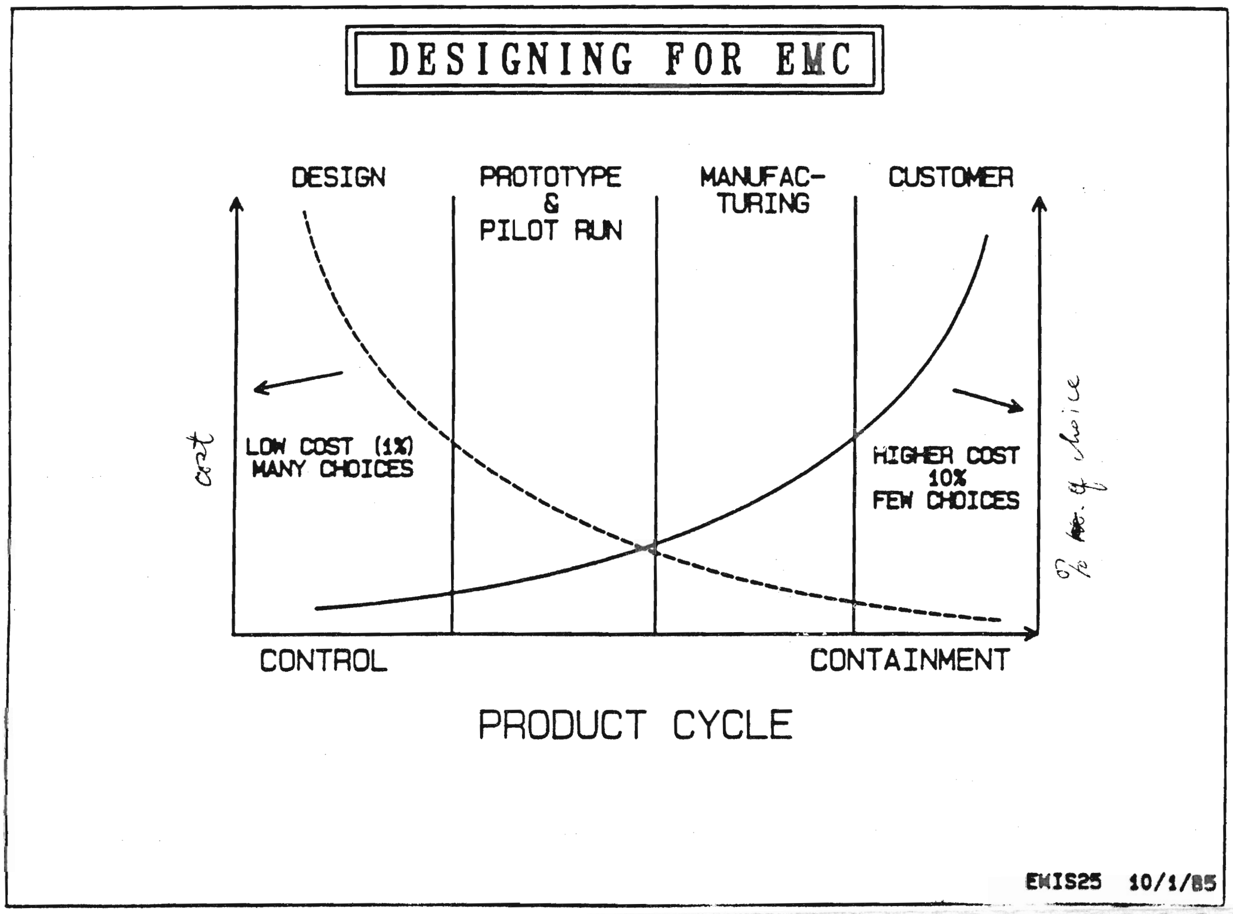
ELECTRIC FIELDS
- LOCAL BROADCAST STATION

[UNDESIRED EM ENERGIES ENTERING SUBJECT UNIT DIRECTLY]

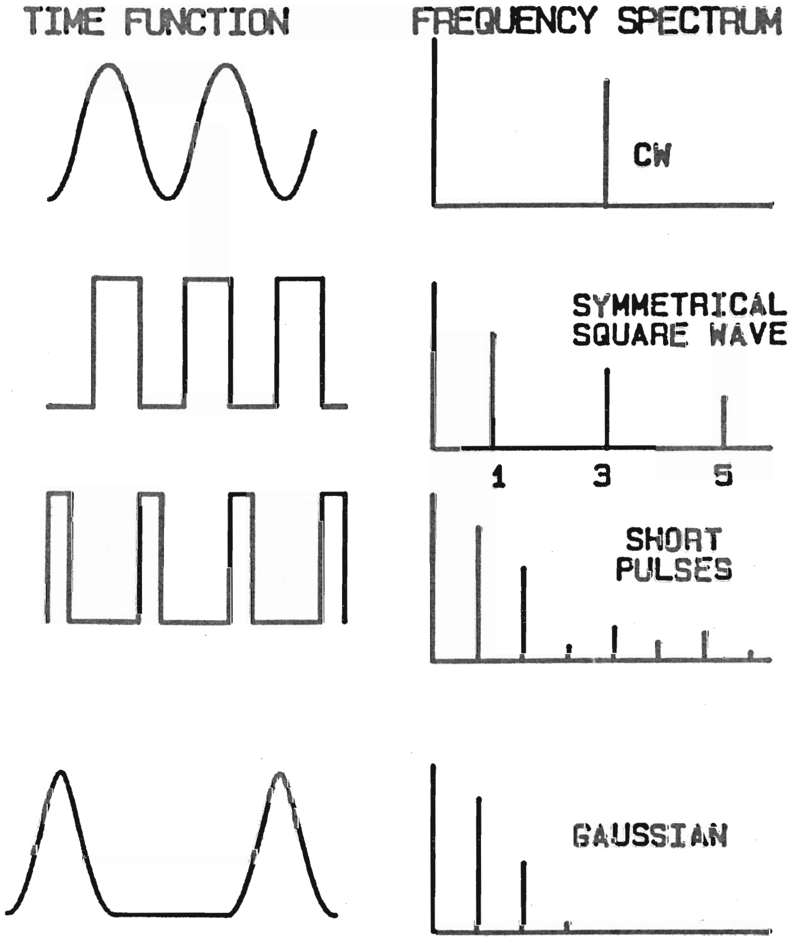
RADIATED EMISSION LIMITS

(NORMALIZED TO 10m ANTENNA DISTANCE BY 1/d)

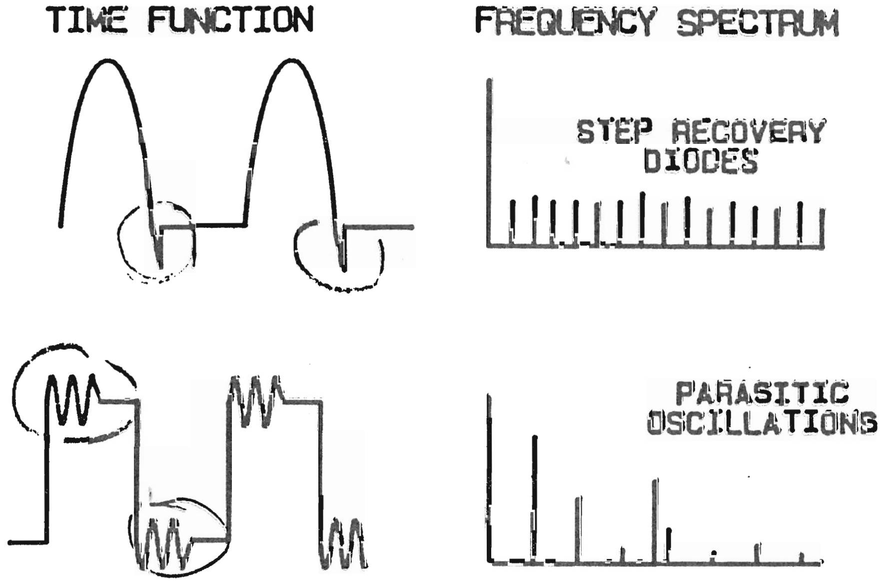




SOURCES OF NOISE: OSCILLATORS, CLOCKS, DIVIDERS, MODULATORS, RELAY CONTACTS, TRIGGERS, ETC.



TIME AND FREQUENCY DOMAINS

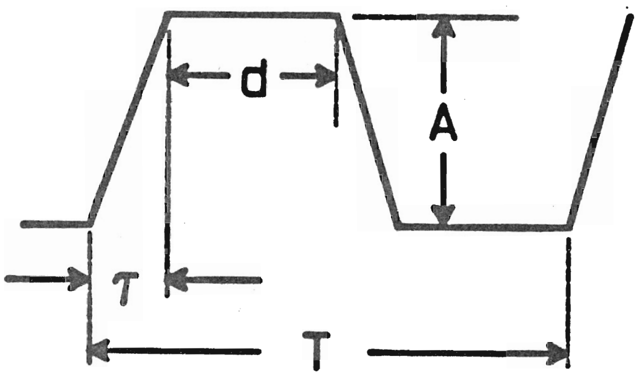


OTHER NOISE WAVEFORMS

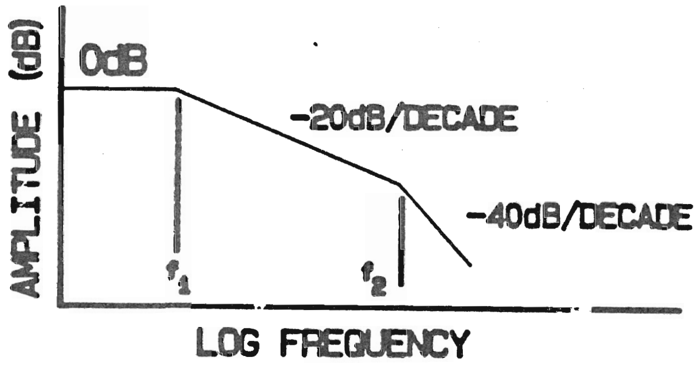
NOISE BANDWIDTH OF COMMON IC's

	RISE TIME v/ηs	INPUT CAPACITANCE pf	Δf 1/πτ mHz
CMOS	0.05	5	3
LP-TTL	0.2	5	21
TTL	0.3	5	32
LS-TTL	0.35	6	40
S TTL	1.0	4	120
ECL-10K	0.4	3	160

TIME TO FREQUENCY DOMAIN



A = AMPLITUDE
d = PULSE WIDTH
τ = RISE TIME
T = PERIOD

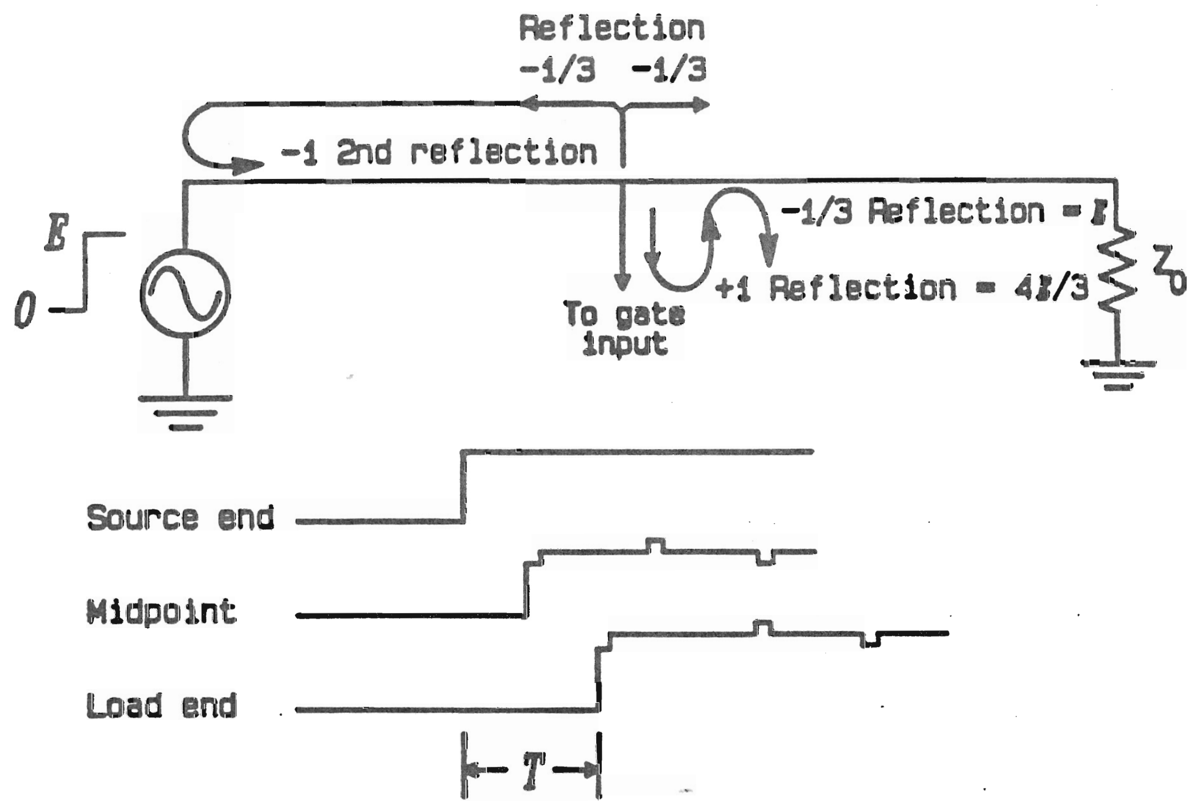


f_0 = FUNDAMENTAL FREQUENCY

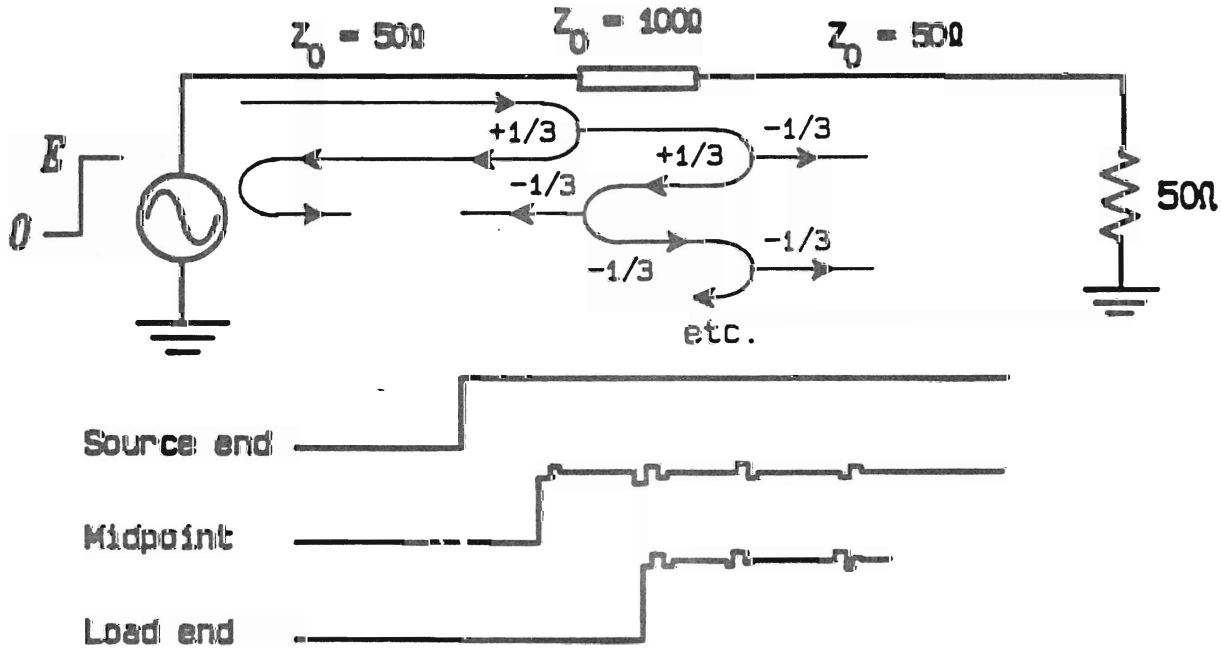
$$f_1 = \frac{1}{\pi (d+\tau)}$$

$$f_2 = \frac{1}{\pi \tau}$$

Reflection From a Stub



Reflection From a Bad Connector



PROPAGATION PATHS FOR NOISE

PC TRACES
TRANSMISSION LINES

WIRES
CABLES

GROUND PLANES
PANELS

GROUND STRAPS
COVERS

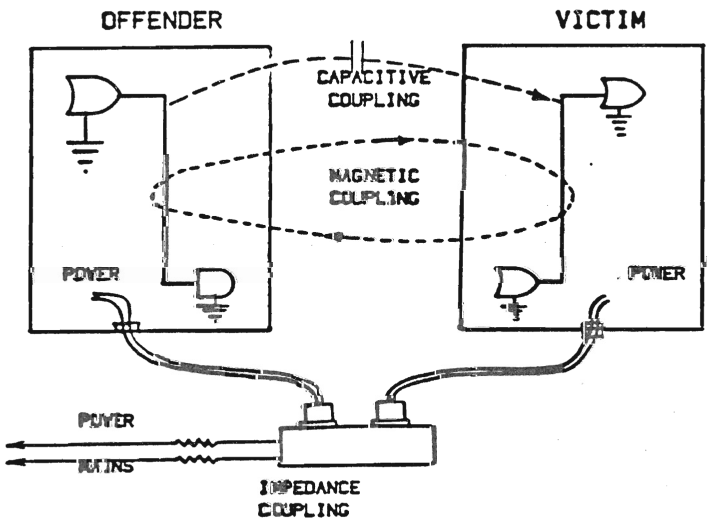
HOLES

SLOTS

SEAMS

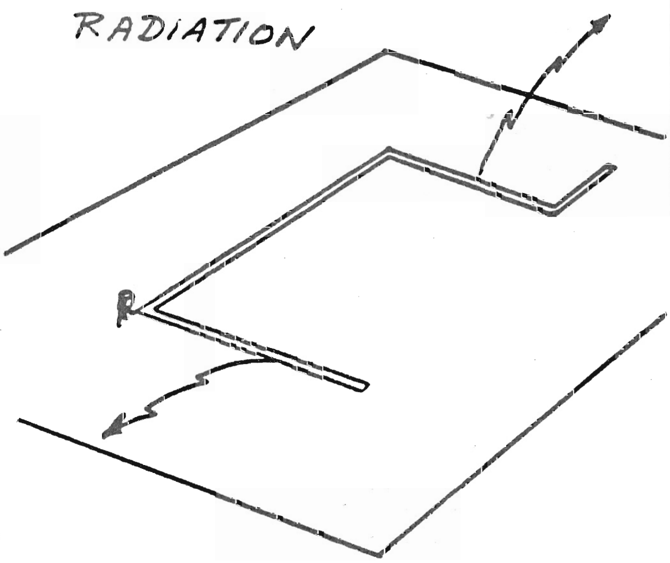
MODES OF COUPLING

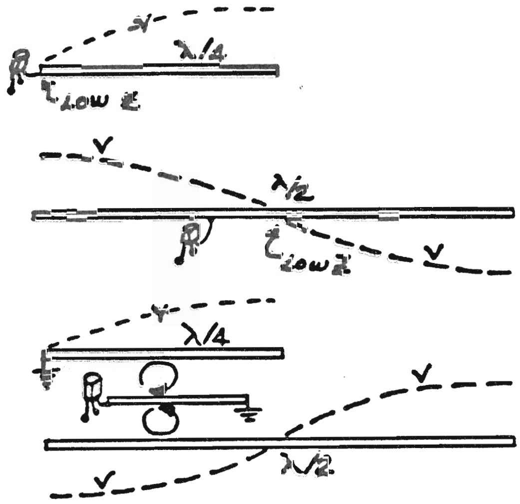
CAPACITIVE COUPLING	(near field)
MAGNETIC COUPLING	(near field)
RADIATION	(far field)
IMPEDANCE COUPLING	
CONDUCTION	



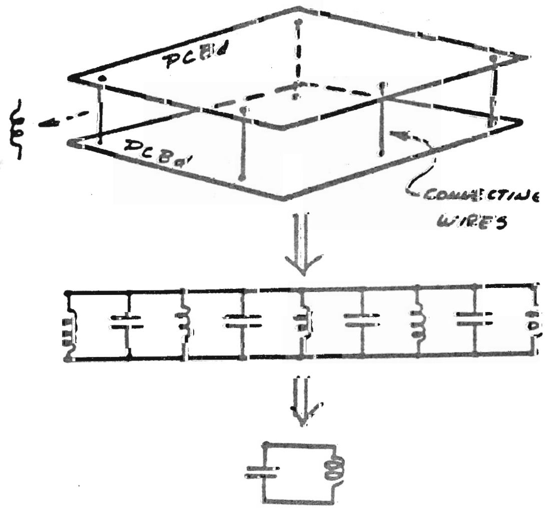
NOISE COUPLING

PRINTED CIRCUIT BOARDS RADIATION



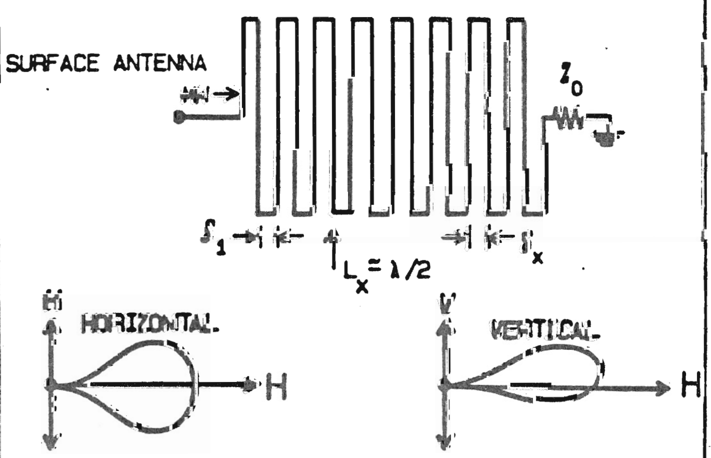


COUPLING INTO RESONATORS



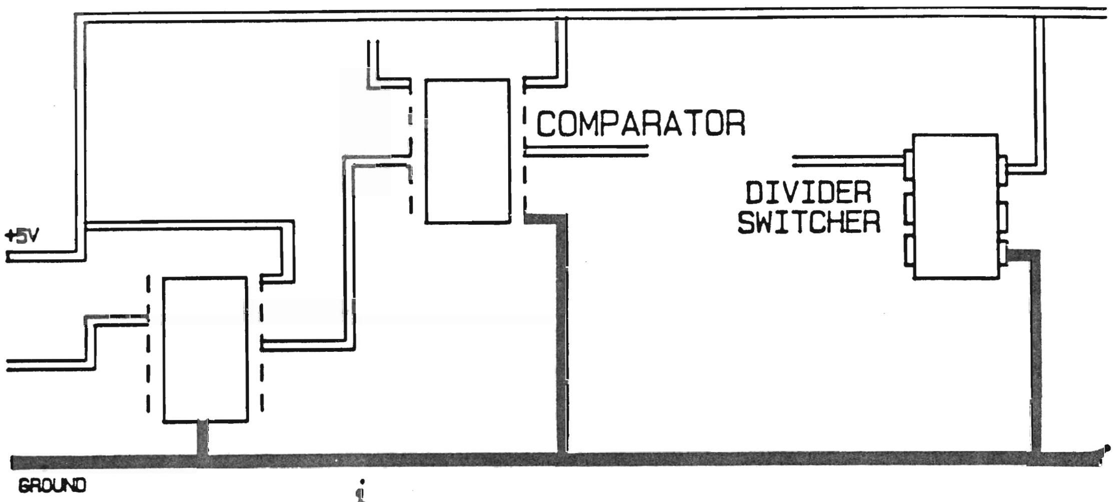
AN UNEXPECTED RESONATOR

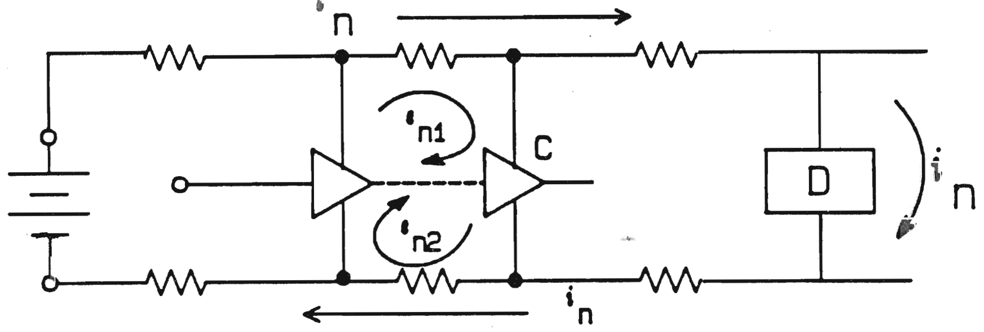
PC BOARD ANTENNA



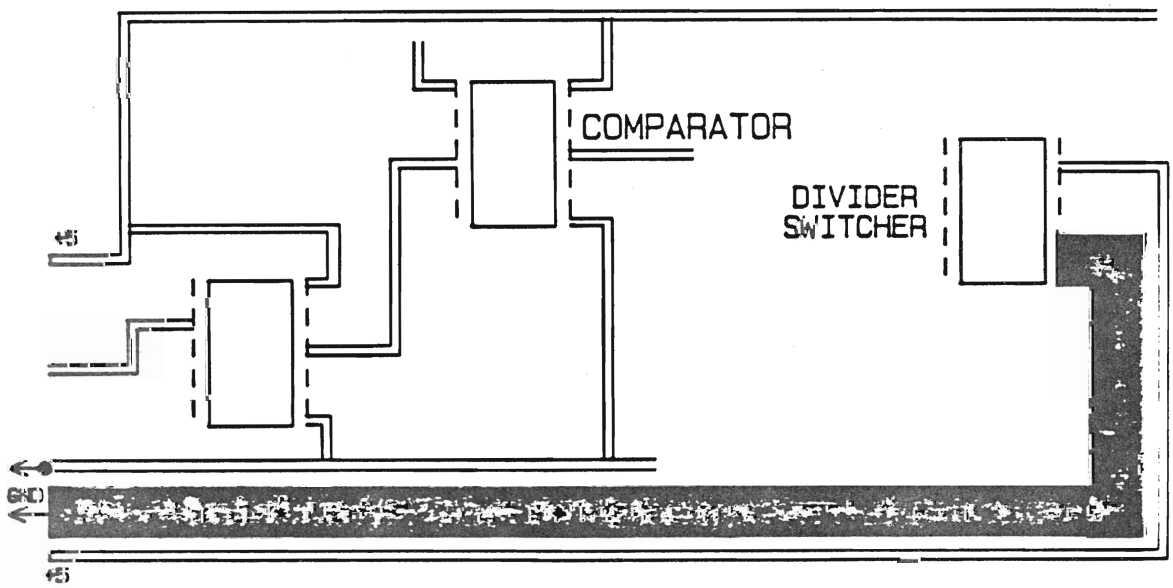
RADIATION PATTERNS

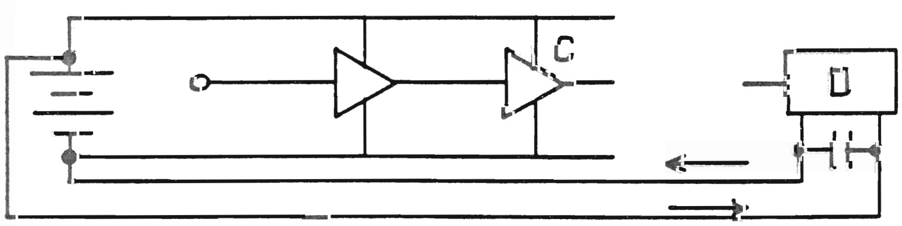
COMMON IMPEDANCE COUPLING



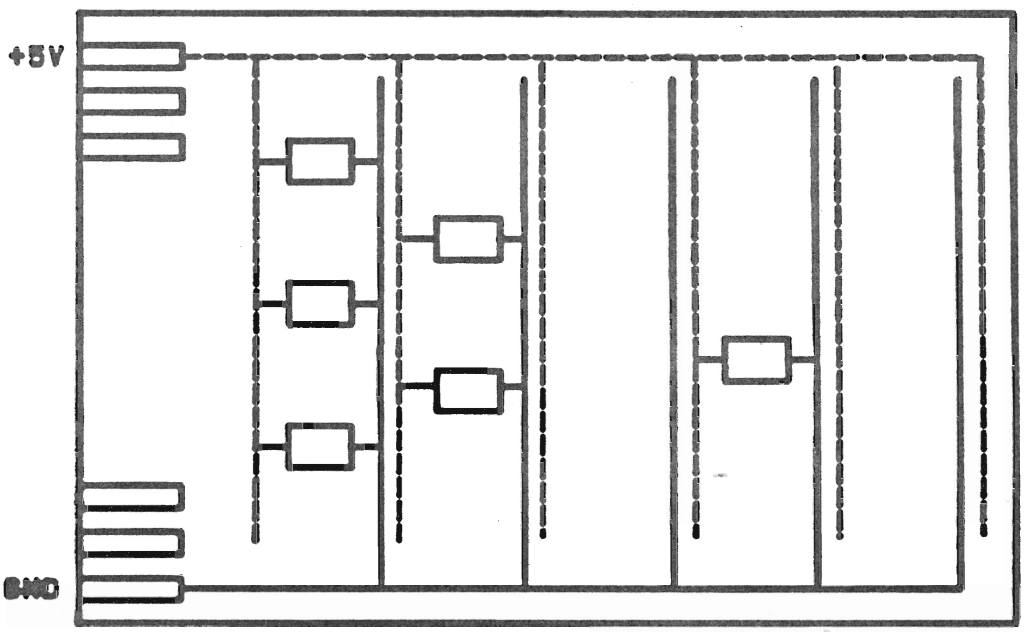


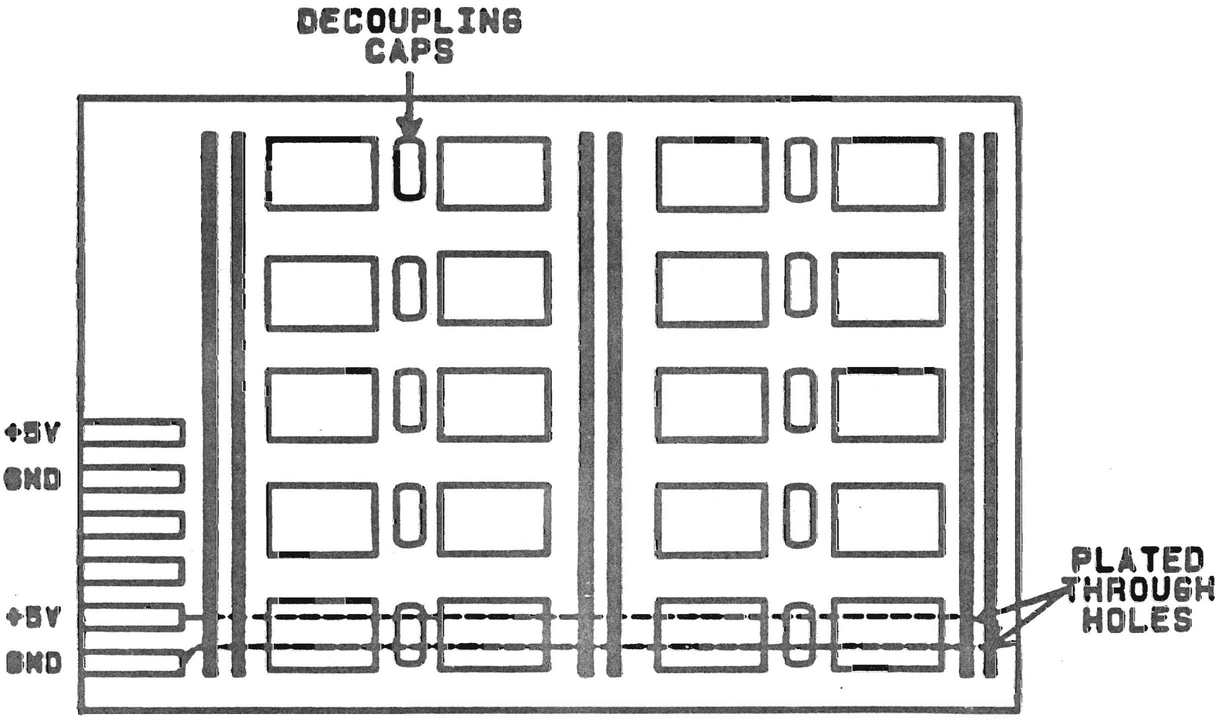
REDUCING COMMON IMPEDANCE COUPLING



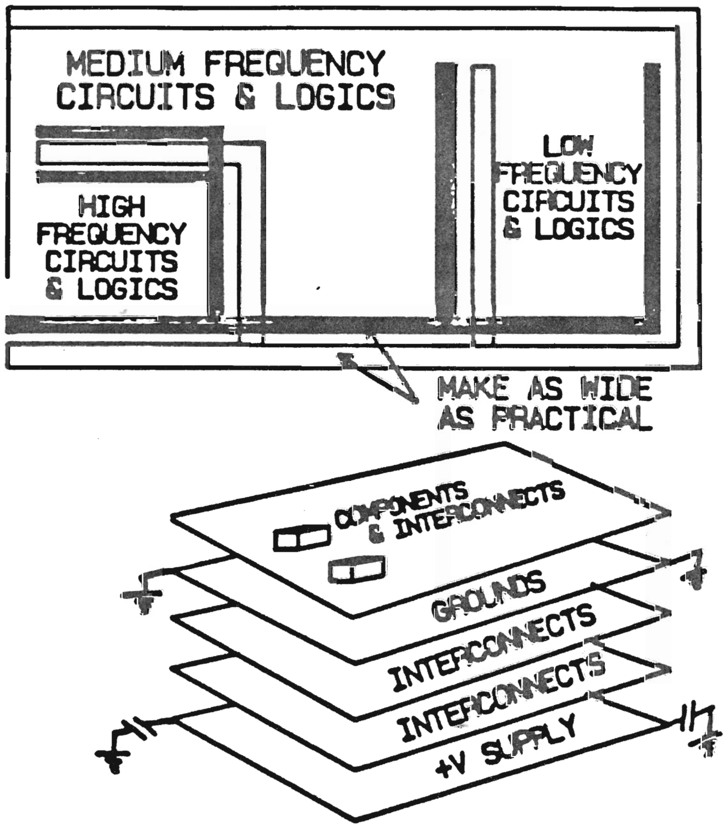


PC LAYOUT CONSIDERATIONS

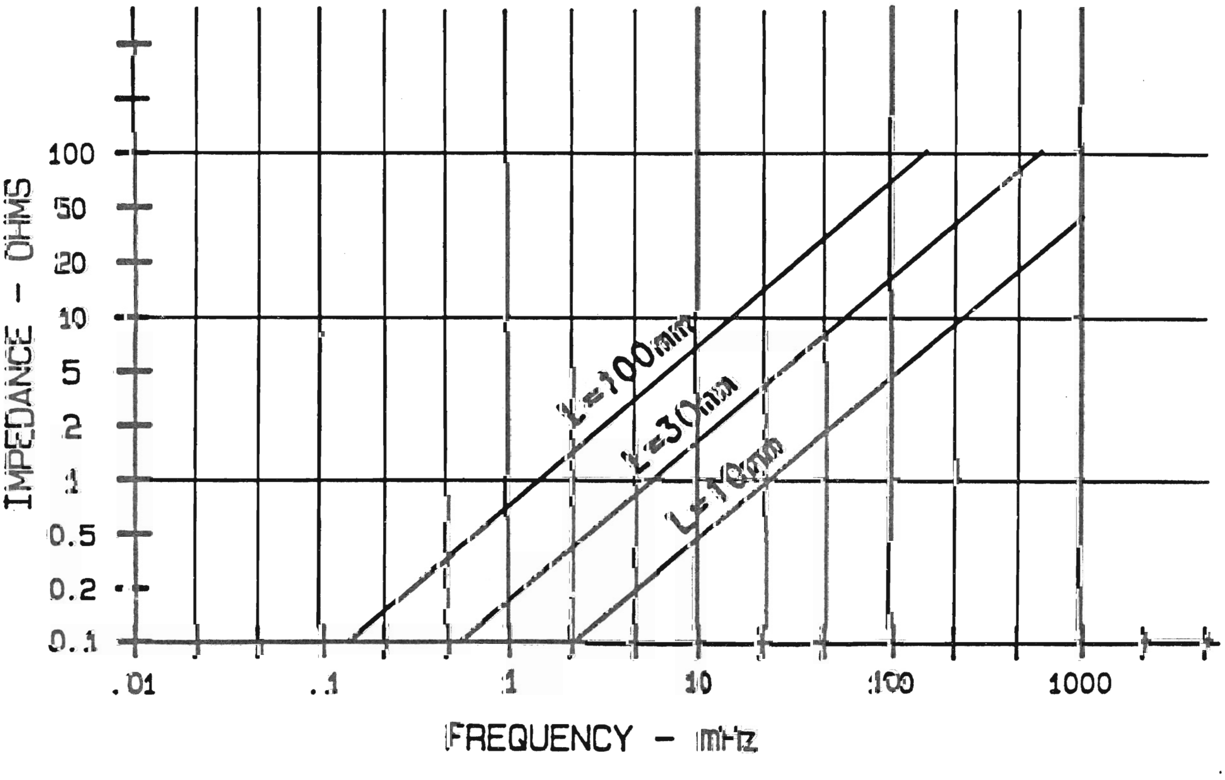


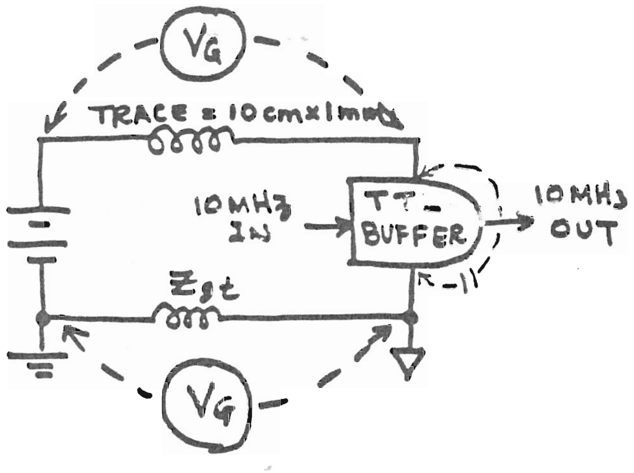


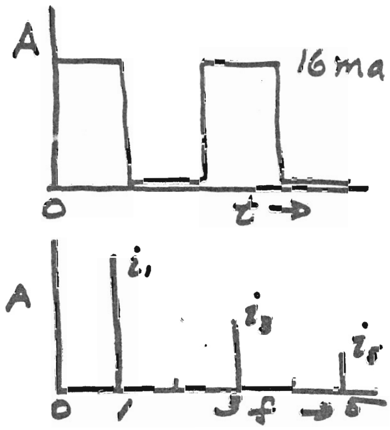
EMISS, 4/15/86



IMPEDANCE OF PC TRACE
Width = 1mm (.04") Thickness = .036mm (.0014")
(USA Copper Foil 1oz)







TYPICAL TRACE: 1MM WIDE. @ 10 MHz, L = 7 OHMS

@ 50 MHz, L = 36 OHMS

IF I_1 (PEAK) = 16 MA, FIFTH HARMONIC I_5 (PEAK) = 2 MA,

THEN V_G = 2 x 36 = 72 MV

LOOK UP CHART: 50 MHz/ 1CM/ 1A = +90 DBµV/M AT 10 M DISTANCE.

FROM CHART: 1MA = .001A = -60 DB
2MA = .002A = 6 DB = -54 DB

IF TRACE IS 10 CM, THEN = +20 DB

TOTAL EFFECTIVE SIGNAL = +56 DBµV/METER

WHAT IS FIELD STRENGTH? +60 DBµV/M = 1 MV/METER.

60 - 56 = 4 DB = RATIO OF 0.63, THEREFORE 56 DBuV = 0.63 MV/M

PCB DESIGN RULES

- AVOID LARGE LOOPS IN TRACES CARRYING CURRENT.
- USE SEPARATE GROUNDS FOR LARGE SIGNALS; MAKE THEM WIDE.
- RUN +V AND GROUND TRACES ADJACENT OR ON OPPOSITE SIDES.
- USE WIDE TRACES FOR +V AND FOR GROUNDS (1MM MIN).
- ON MULTILAYER BOARDS PLACE EMI CRITICAL TRACES BETWEEN +V & GND.
- CUT CORNERS TO REDUCE REFLECTIONS ON TRACES CARRYING FAST PULSES.
- CHOOSE AS SLOW A LOGIC COMPONENT AS POSSIBLE.
- USE DECOUPLING CAPACITORS BETWEEN EACH PAIR OF IC's. KEEP LEADS SHORT. CHOOSE CAPACITORS WITH HIGH ENOUGH OF RESONANCE FERQUENCY.
- FOR SWITCHING POWER SUPPLIES, LOCATE TRACES DIRECTLY ON OPPOSITE SIDES OF THE PCB TO REDUCE THE LOOP AREA.

CHECKLIST FOR MINIMIZING E M I

1. ELIMINATION OF SOURCE
2. ISOLATION
3. ORIENTATION
4. SHIELDING
5. FILTERING
6. GROUNDING
7. BALANCING
8. IMPEDANCE LEVEL CONTROL
9. CABLE DESIGN
10. CANCELLATION TECHNIQUES

ELIMINATION BY SIGNAL CONDITIONING

- LIMIT AMPLITUDE
- LIMIT RISE TIME/FALL TIME
- DISTRIBUTE SINE WAVE; SHAPE AT LOAD
- CHOOSE WAVEFORM FOR COMPATIBLE HARMONIC CONTENT

  e.g., USE SYMMETRICAL WAVE; NO EVEN HARMONICS

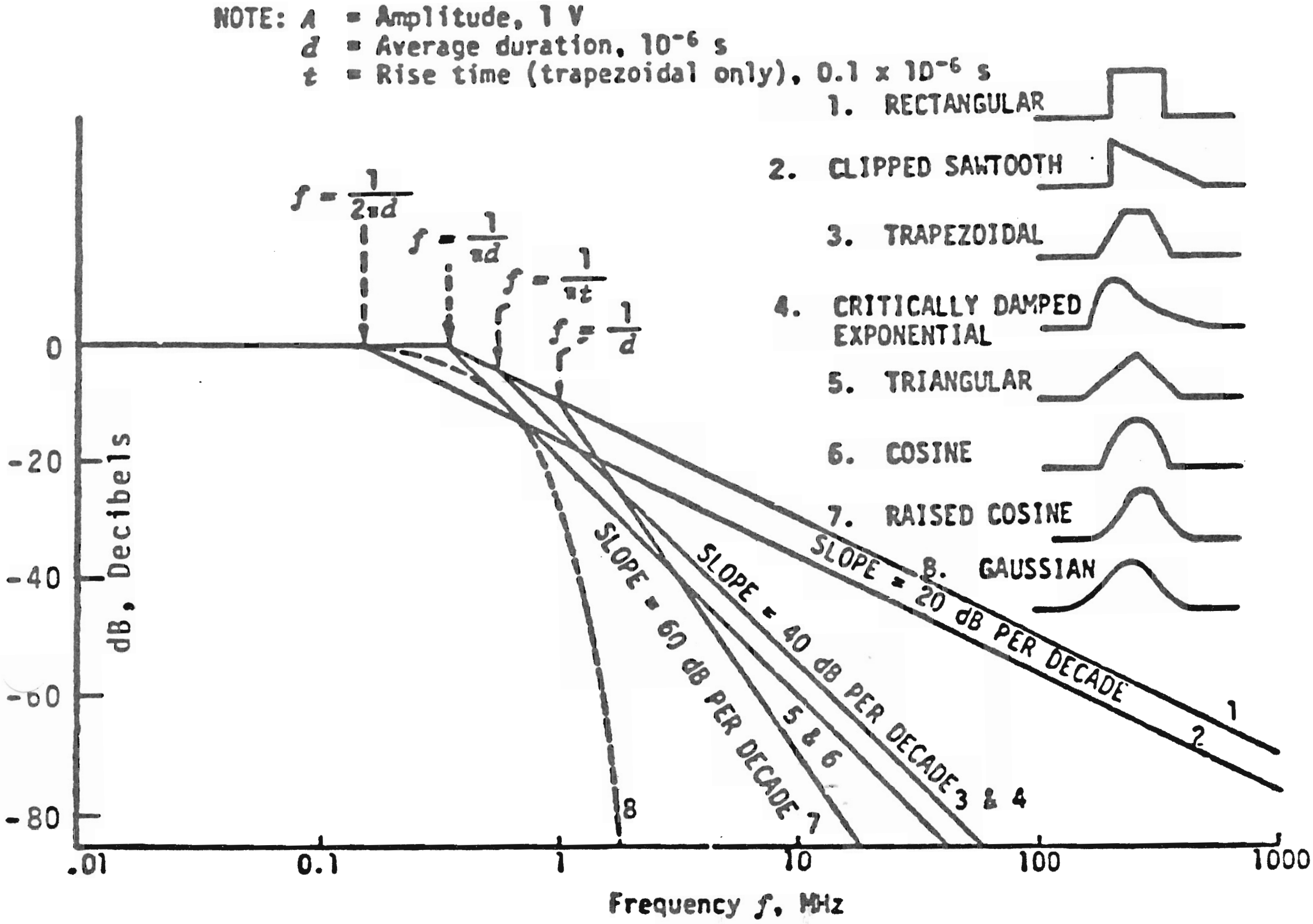
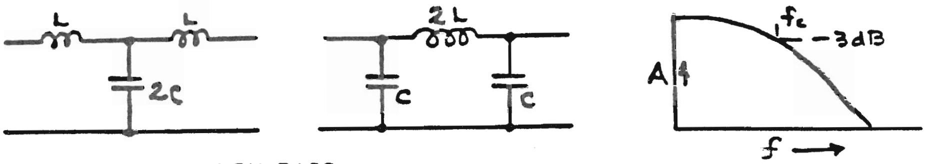
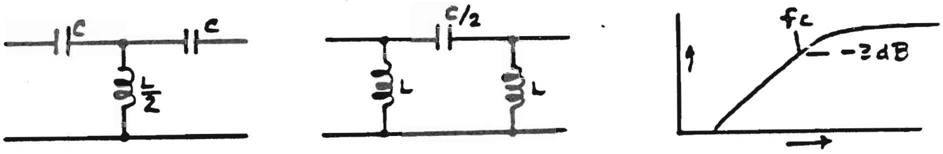


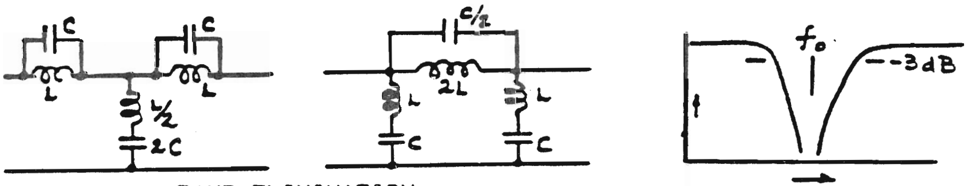
Figure 4-1. Interference Levels for Eight Common Pulses



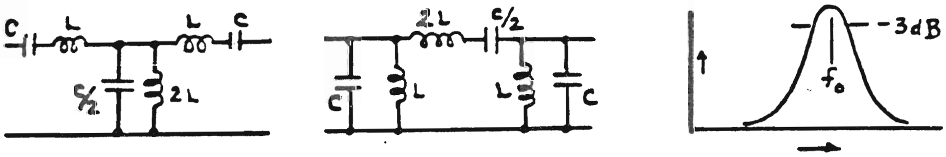
LOW PASS



HIGH PASS

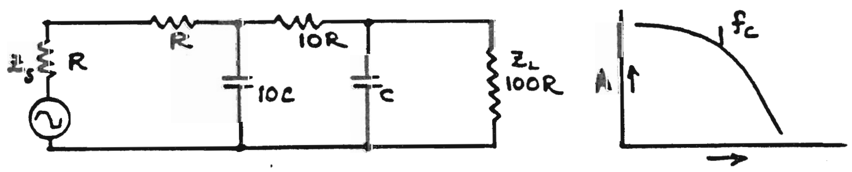


BAND ELIMINATION



BAND PASS

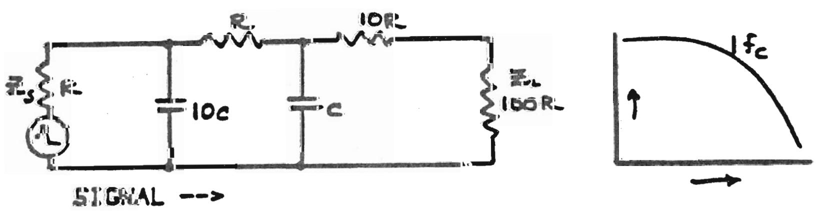
LC FILTERS



SIGNAL -->

ATTENUATE HF -->

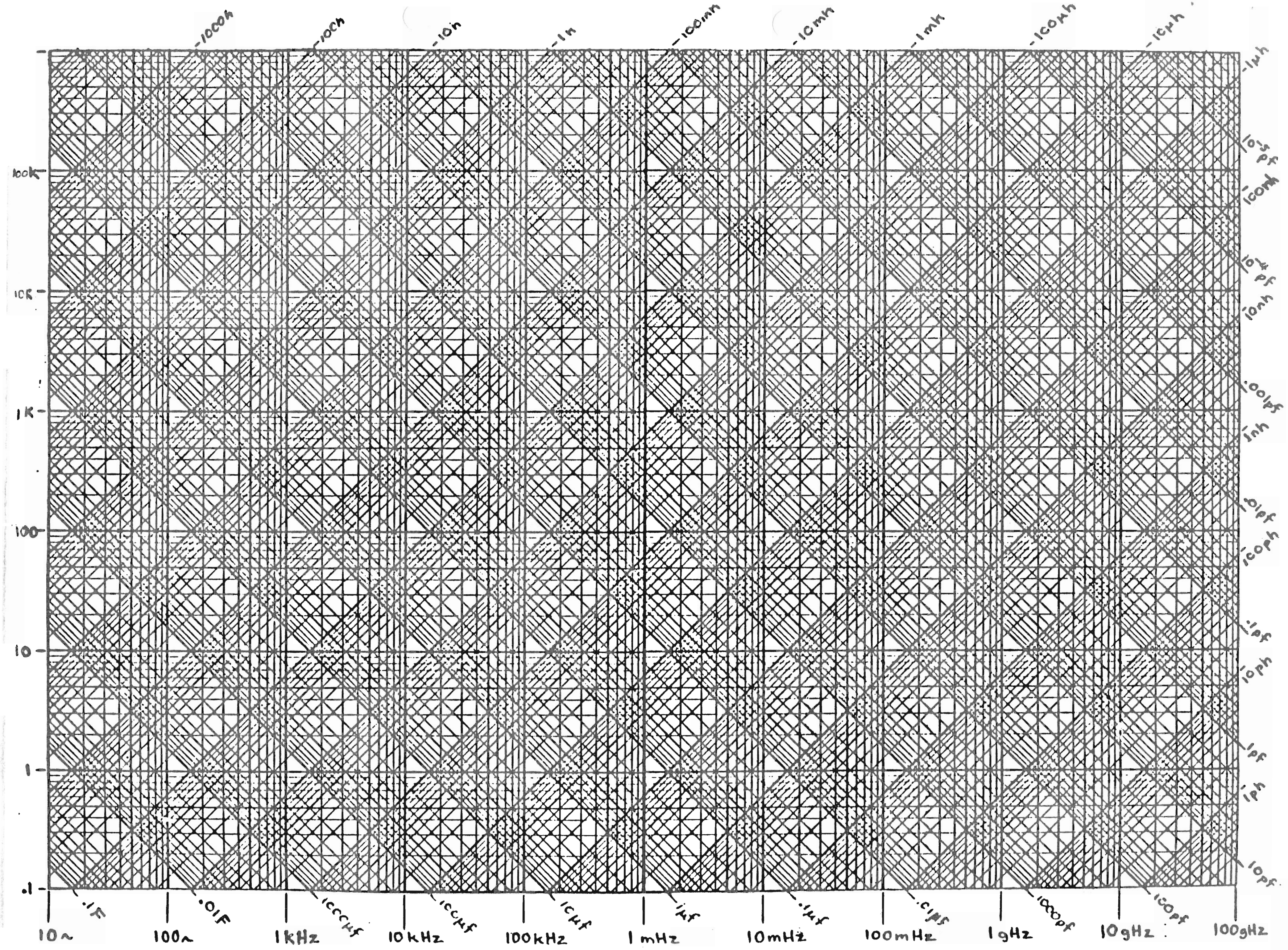
$$f_c \approx \frac{1}{2\pi RC}$$



SIGNAL -->

<-- ATTENUATE HF

RC LOW PASS FILTERS



1000h
100h
10h
1h
100mh
10mh
1mh
100µh
10µh
1µh
10^{-5} pf
100nh
10^{-4} pf
10nh
.001pf
1nh
.01pf
100ph
.1pf
10ph
1pf
1ph
10pf
100k
10k
1k
100
10
1
.1
.1F
.01F
1000µf
100µf
10µf
1µf
.1µf
.01µf
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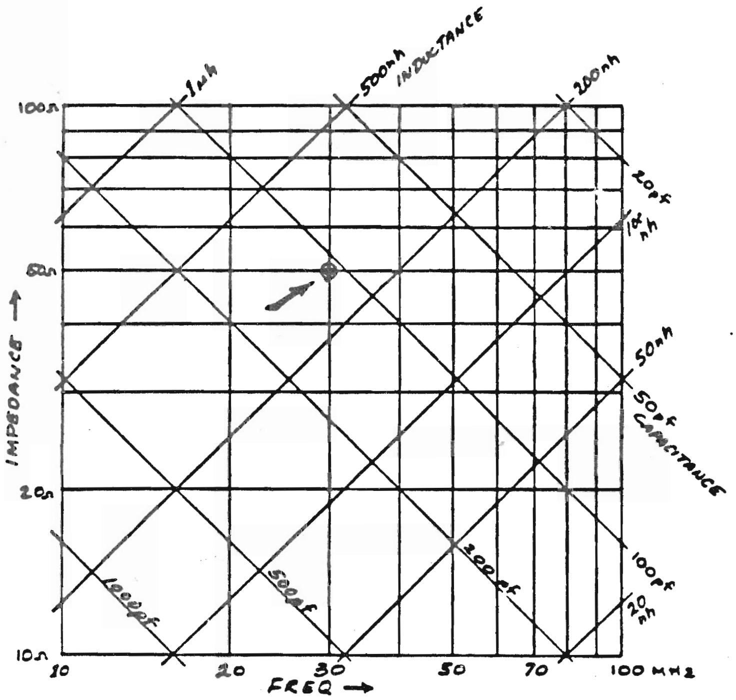
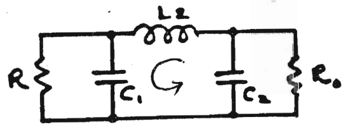
100mHz
1gHz
10gHz
100gHz



$f_c = \frac{1}{2\pi\sqrt{LC}}$ = 30 MHz

$Z = \sqrt{L/C}$ = 50Ω

L = ? = 265nh   C = ? = 106pf



DESIGN TABLE FOR:
$R_0 = 1$, $\omega_c = 1$ AT −3dB

R/R_0	C_1	L_1	C_3	$\left[\omega_c' = \frac{1}{\sqrt{LC'}}\right]$
0	.50	1.33	1.50	----
1/8	12.44	.174	4.17	1.17
1/4	6.39	.361	2.17	1.13
1/3	4.85	.493	1.67	1.10
1/2	3.26	.779	1.18	1.04
1	1	2	1	----

LOUIS WEINBERG: NETWORK SYNTHESIS

EXAMPLE: $R_0 = 50\Omega$ $f_c = 10^7$ Hz $\omega_c = 2\pi f_c$

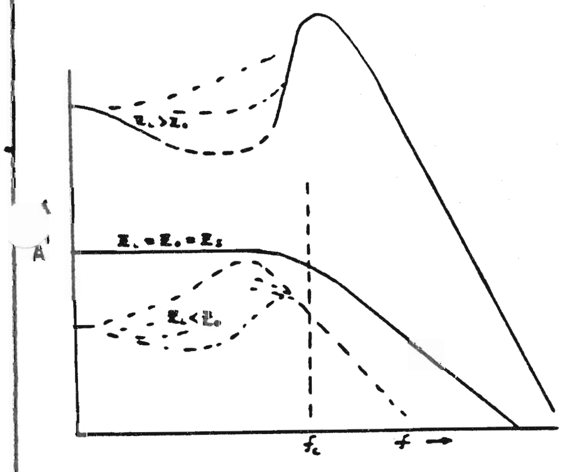
$C_n' = C_n / R_0 \omega_c$ $L_n' = L_n R_0 / \omega_c$

$R/R_0 = 1$ $C_1 = 1/50(2\pi 10^7) = 318\times10^{-12}$ F $L_2 = 2(50/2\pi 10^7) = 1.6\times10^{-6}$ H

$C_2 = C_1$

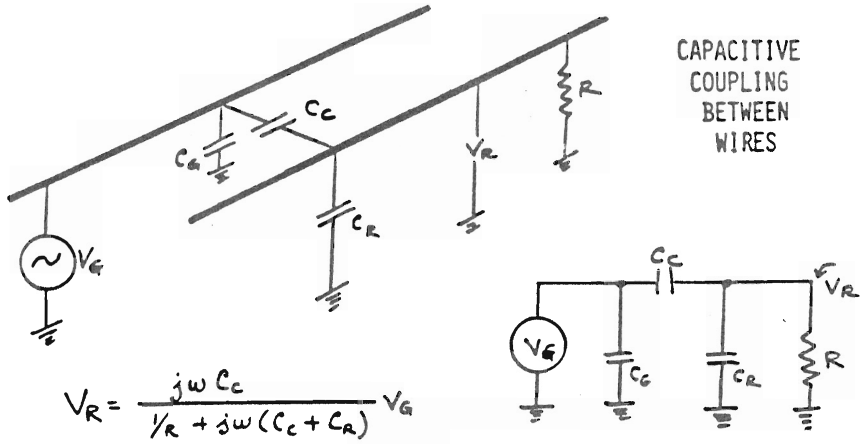
$R/R_0 = 1/4$ $C_1 = 6.39/50(2\pi 10^7) = 2030$ pf $L = .361(50/2\pi 10^7) = .287\ \mu$H

$C = 2.17/50(2\pi 10^7) = 690$ pf



UNFIT RESPONSE DUE TO
MISMATCHED TERMINATIONS

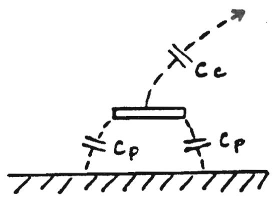
LOW PASS FILTER.
UNEQUAL IMPEDANCES

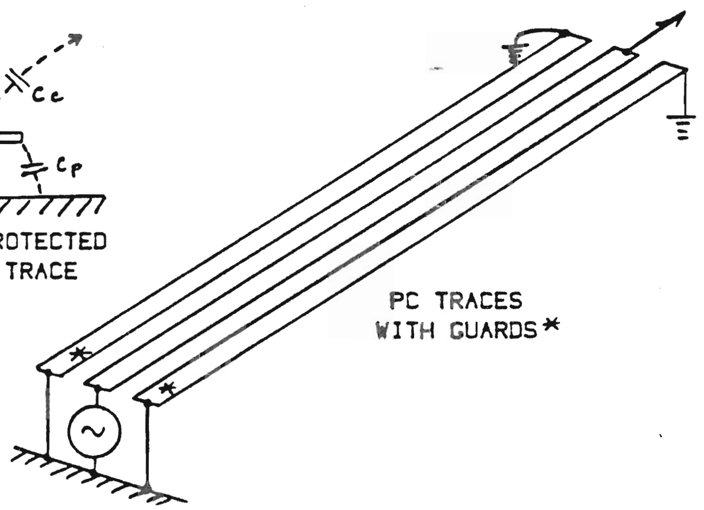


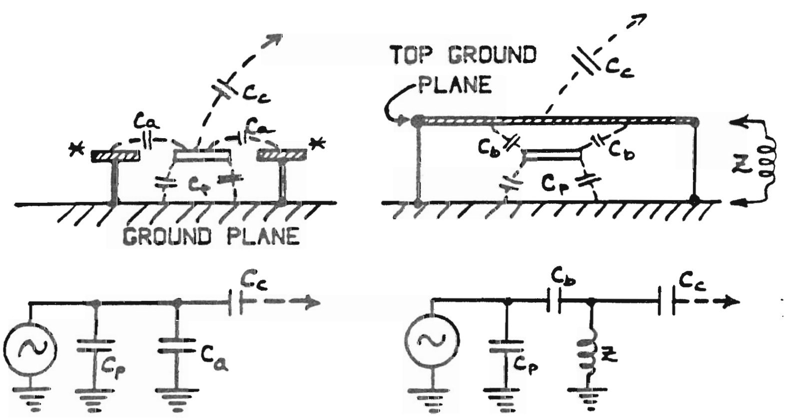
$$V_R = \frac{j\omega C_c}{1/R + j\omega(C_c + C_R)} V_G$$

IF $R < 1/j\omega(C_c + C_R)$

THEN $V_R = j\omega R C_c V_G$



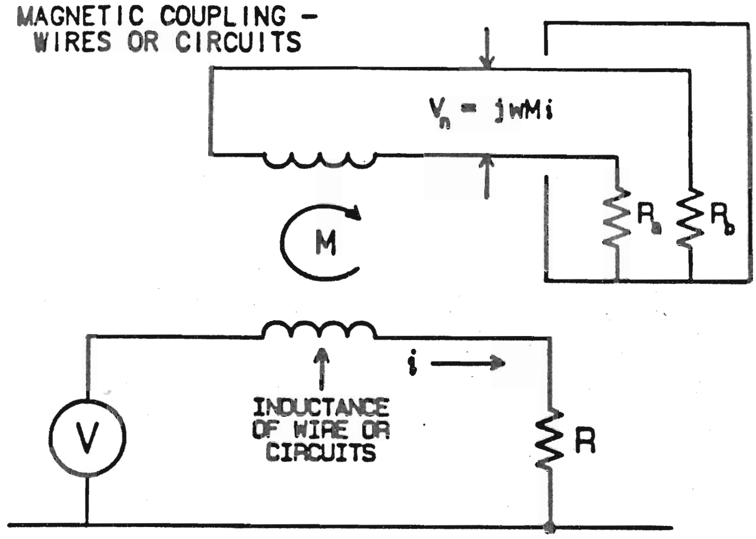




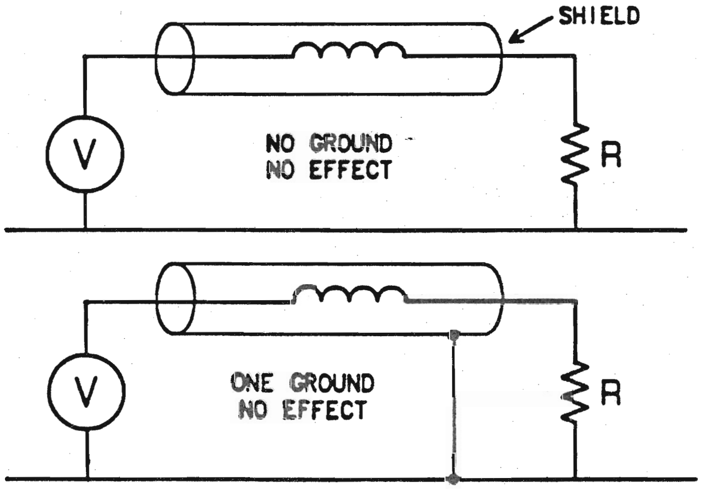
SHIELDING PC TRACES

EMC 3/4/82

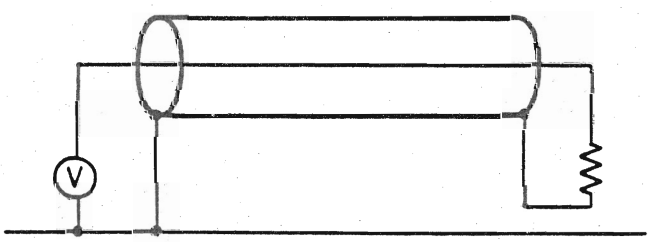
MAGNETIC COUPLING -
WIRES OR CIRCUITS



MAGNETIC COUPLING - WIRES OR CIRCUITS



CURRENT RETURN THROUGH SHIELD

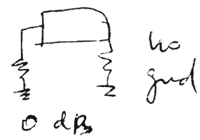


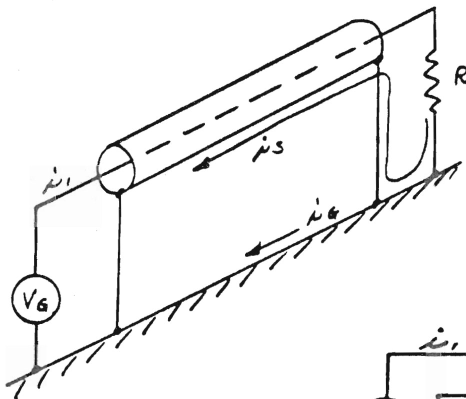
NO CURRENT THROUGH GROUND
NO LOOP TO RADIATE

CUTOFF FREQUENCIES OF COMMON CABLES

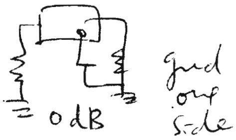
COAXIAL CABLES	IMPEDANCE (ohms)	CUT OFF FREQUENCY (kHz)
RG-213 (RG-8) **	50	0.7
RG-214 (RG-9) **	50	0.7
RG-223 (RG-55) **	50	2.0
RG-58 * microwave use	50	2.0
RG-6A ** Cable TV use	75	0.6
RG-59 **	75	1.6
RG-62A *	93	1.5
RG-71B **	93	1.5
TWISTED PAIR *	--	0.8-4.0

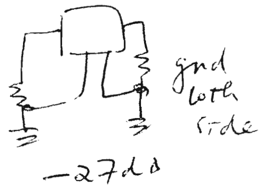
* Single shield
** Double shield

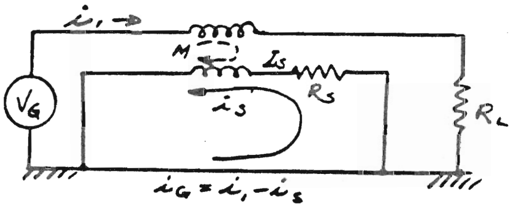




CURRENT DIVISION BETWEEN SHIELD & GROUND PLANE







MESH EQUATION: $i_S(j\omega L_S + R_S) - i_1(j\omega M) = 0$

$$i_S = i_1\left(\frac{j\omega M/L_S}{j\omega + R_S/L_S}\right) = i_1\left(\frac{j\omega M/L_S}{j\omega + \omega_c}\right)$$

$\omega_c = R_S/L_S$

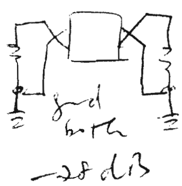
higher freq. better

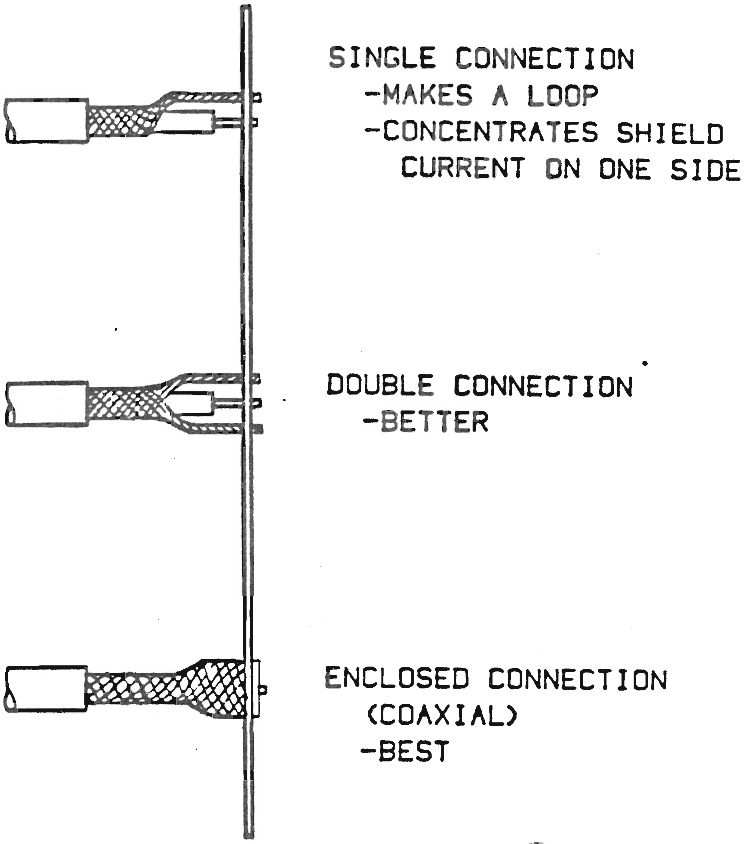
AT $\omega > \omega_c$ LESS RADIATION

BELOW $\omega < \omega_c$ MORE RADIATION

$$i_G = i_1\left(1 - \frac{M}{L_S}\right)$$

$$i_G = i_1\left(1 - \frac{\omega}{\omega_c}\frac{M}{L_S}\right)$$

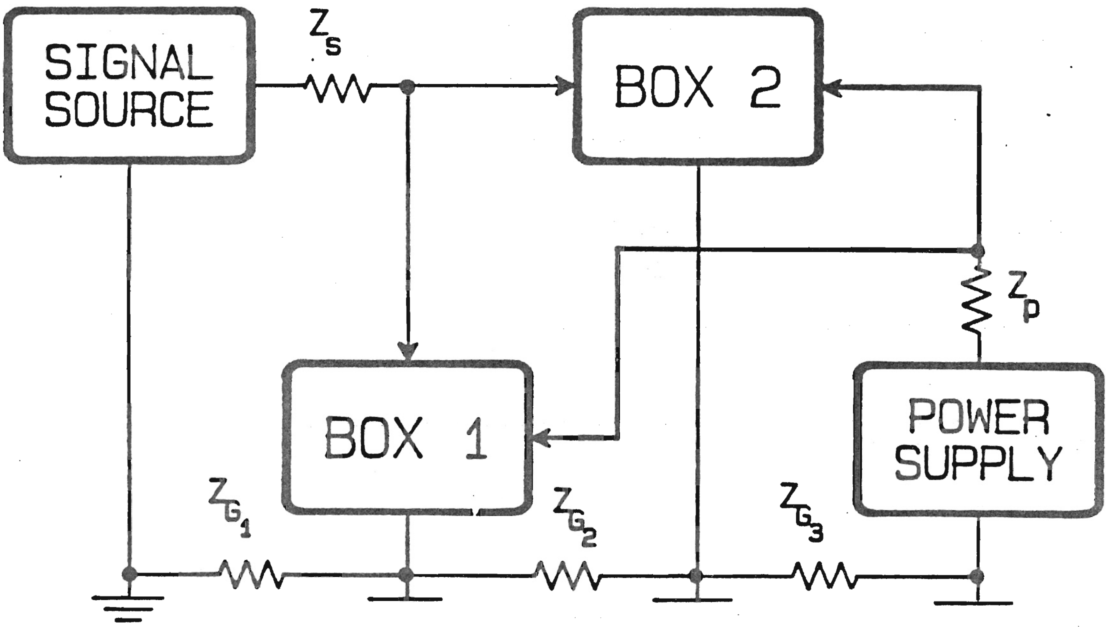




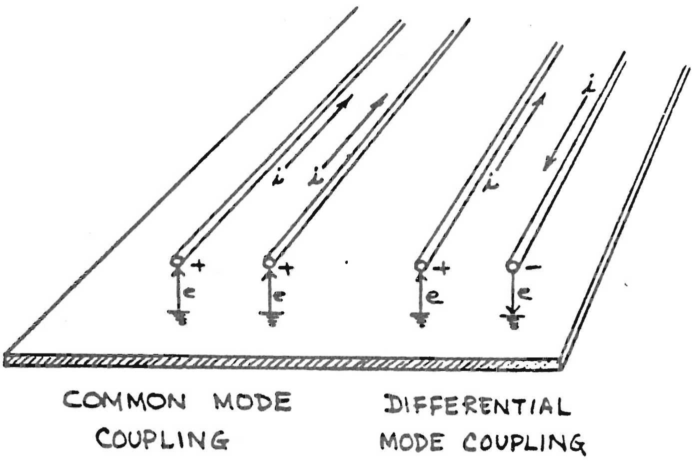
SHIELD GROUNDING TECHNIQUES

PRINCIPLE EMI COUPLING PATHS (cont'd)

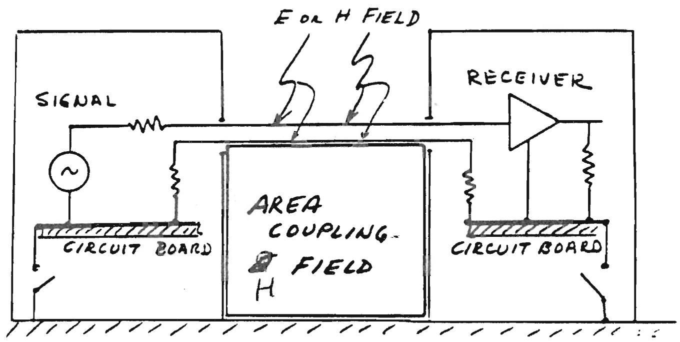
CONDUCTED EMI:



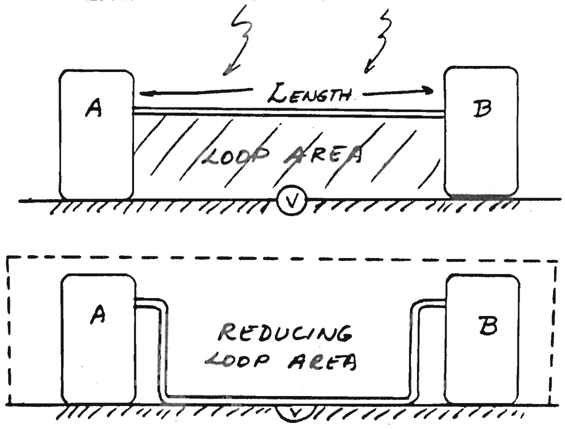
CMC AND DMC



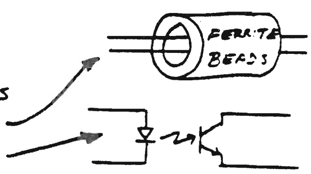
COMMON MODE COUPLING



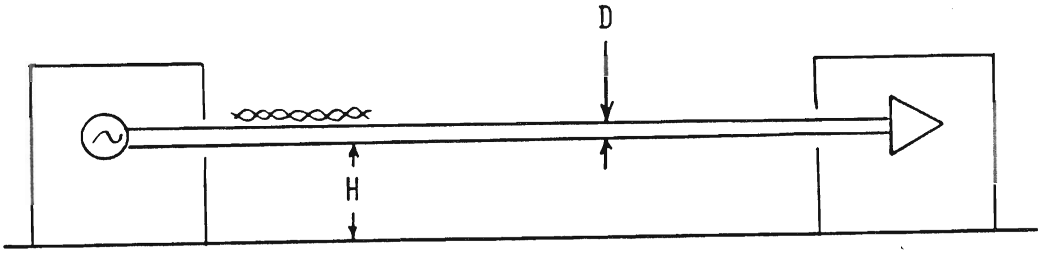
REDUCING COMMON MODE COUPLING



1. REDUCING LOOP AREA.
2. REDUCING LENGTH
3 SHIELD BOTH BOXES
4. SELECTIVE FILTERING.
5. OPTICAL ISOLATORS



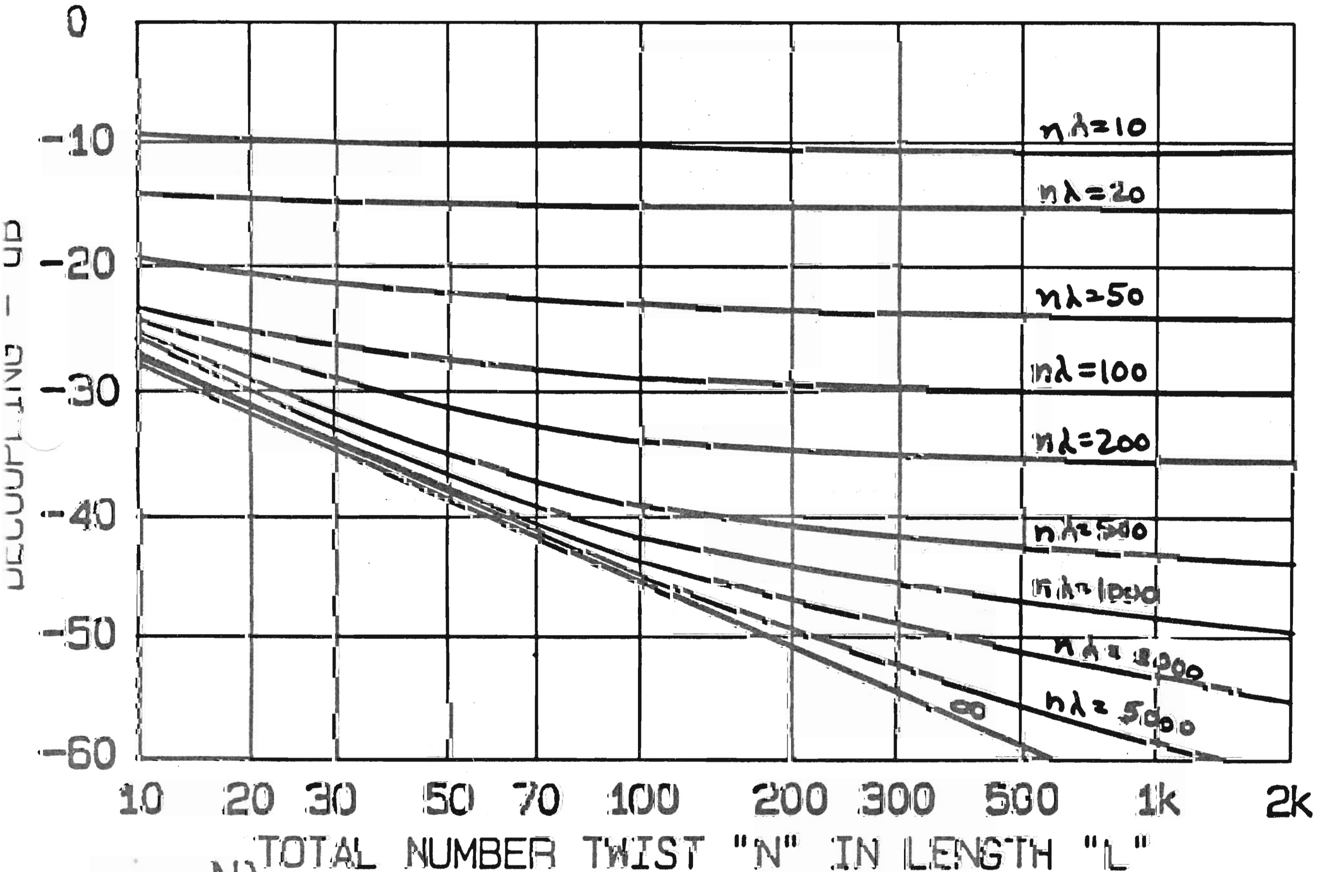
DIFFERENTIAL MODE COUPLING



EMI REDUCTION FOR WIRE PAIRS

- REDUCE SPACING OF WIRES
- TWIST WIRE PAIRS
- ADD BRAIDED SHIELD OR SOLID SHIELD

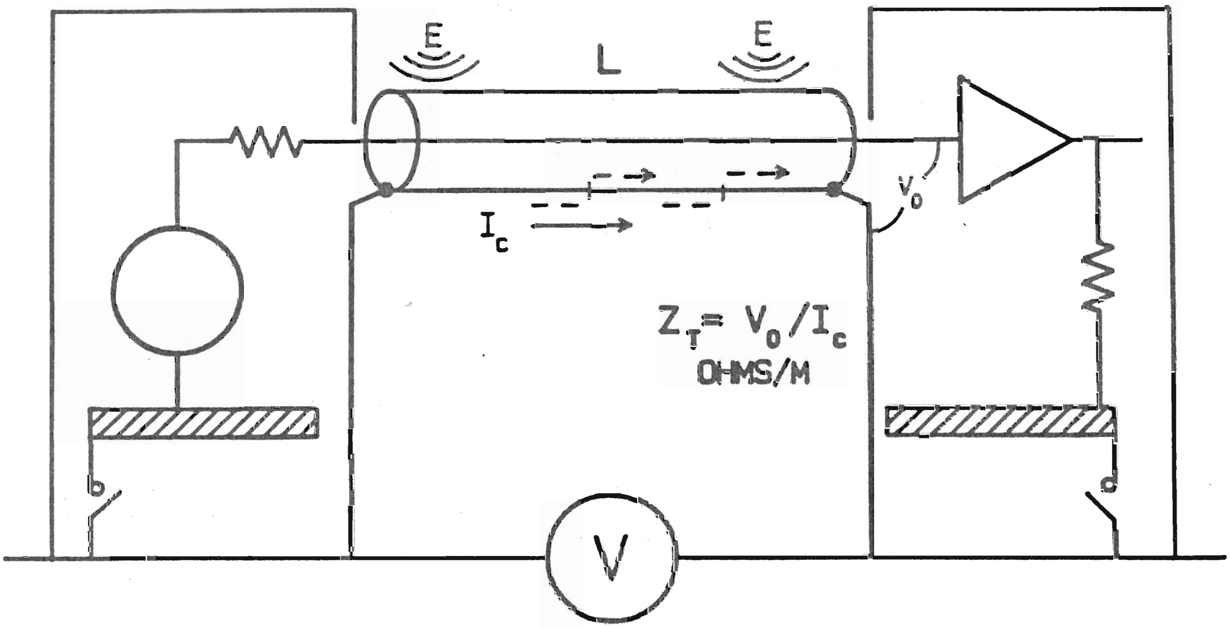
DECOUPLING IN TWISTED WIRE PAIR



$n\lambda = \frac{N\lambda}{l}$ = (TWIST PER METER) x (WAVELENGTH IN METERS)

DECOUPLING = $-20\log_{10}\left(\frac{1}{2nl+1}\right)\left[1+2nl\sin\left(\frac{\pi}{n\lambda}\right)\right]$ dB

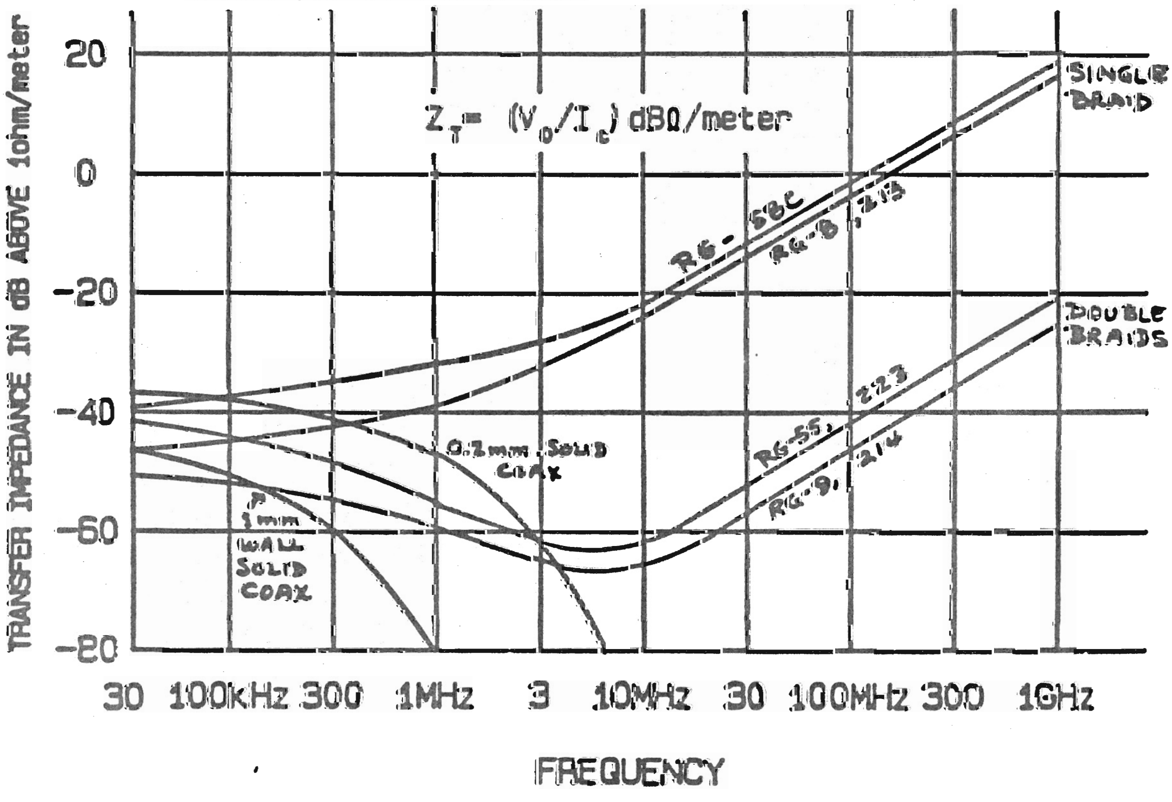
DIFFERENTIAL MODE COUPLING IN COAXIAL CABLE



$$DMC_{DB} = 20\ LOG_{10}\ [(I_c/E)\ (V_0/I_c)] = 20\ LOG_{10}\ [(I_c/E)\ Z_T]$$

$$I_c/E = 3.9 \times 10^{-5}\ L^2 F_{MHZ} \qquad \text{FOR } L/\lambda \leq 0.5$$

TRANSFER IMPEDANCE OF CABLES



4-85

GROUNDING

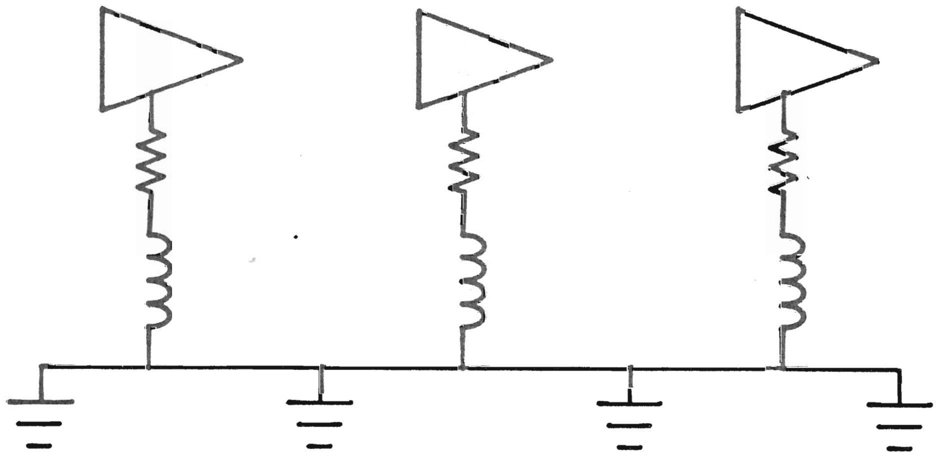
A GOOD GROUND SYSTEM MUST BE DESIGNED, NOT LEFT TO CHANCE

IMPORTANT POINTS

1. CURRENT FLOW
2. FINITE IMPEDANCE
3. VOLTAGE DIFFERENTIAL
4. PATH TAKEN BY CURRENT

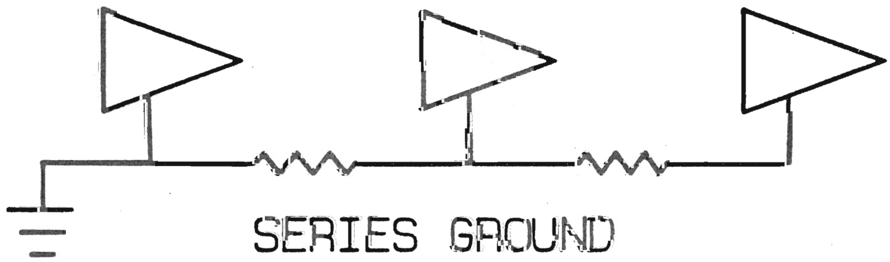
[illegible] 4/16/85

MULTI-POINT GROUNDING (F>10MHz)

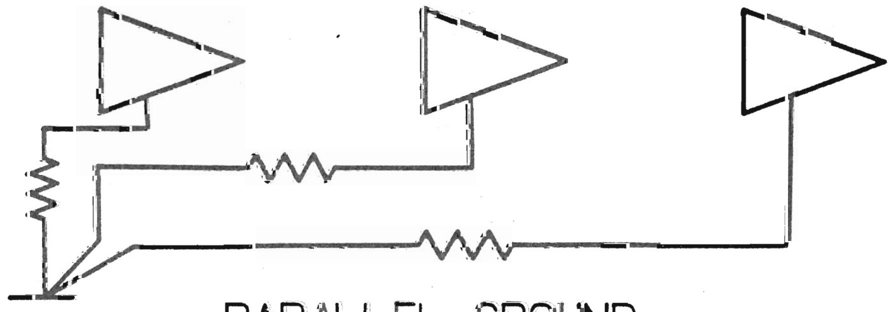


USEFUL FOR HIGH FREQUENCIES (Line length>λ/20)
(Comparable to 600 MHz-in or 1.5 GHz-cm)

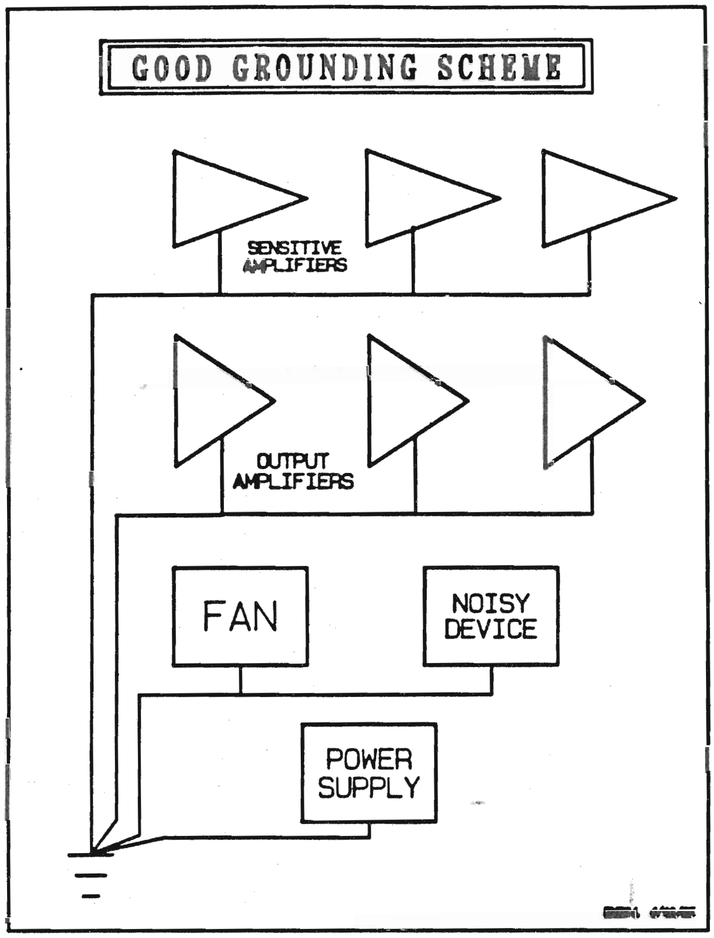
SINGLE POINT GROUNDING (LOW FREQ)



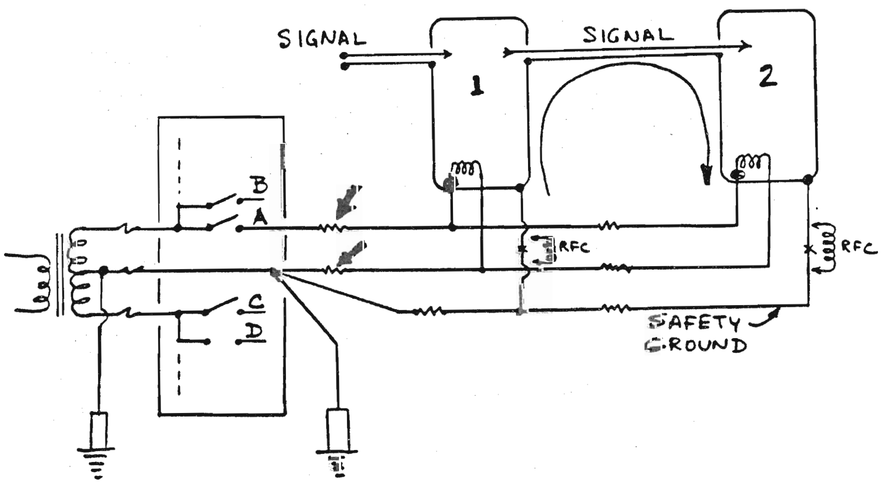
SERIES GROUND



PARALLEL GROUND

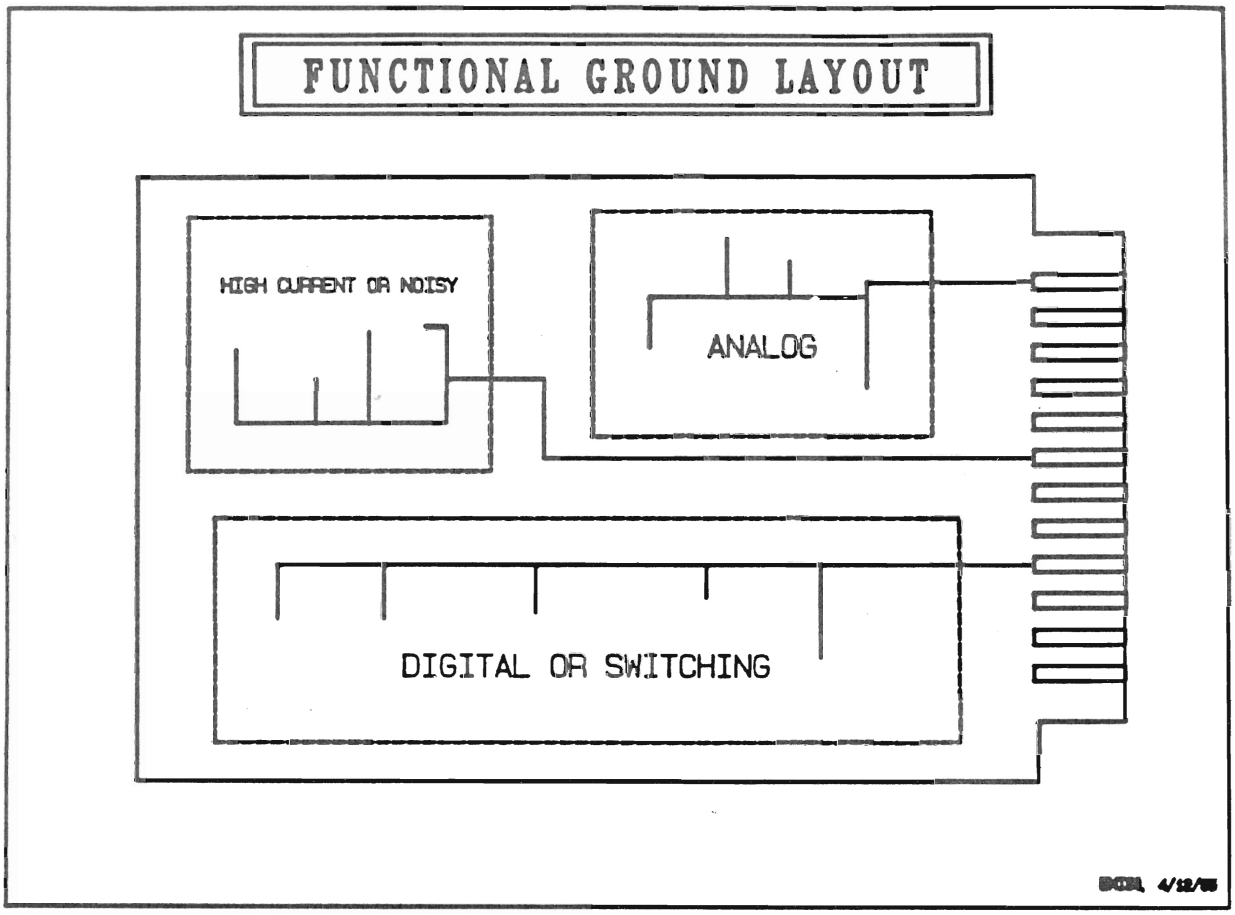


EMI CONTROL IN POWER MAINS



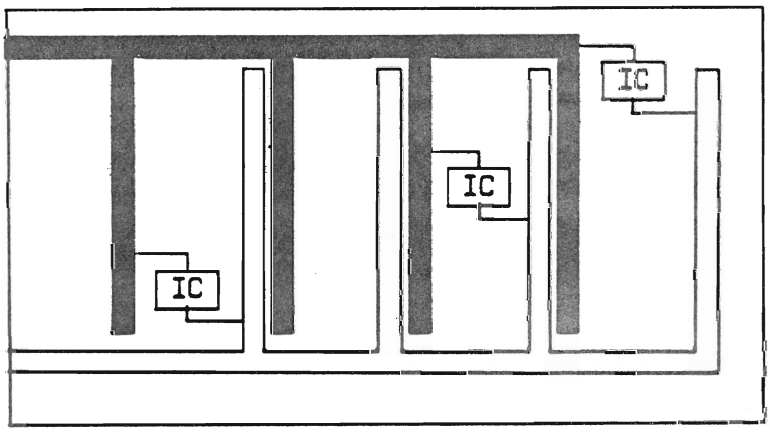
SOME POSSIBLE SOLUTIONS:

1. USE SEPARATE POWER LINES FROM BOX 2 TO A
2. " " " " " " " B
3. " " " " " " " C
4. PLACE FILTERS ON POWER LINES AT EQUIPMENT.
5. USE ISOLATION TRANSFORMER ON POWER LINES.
6. USE R-F CHOKES (INDUCTORS) IN SAFETY GROUND WIRE.



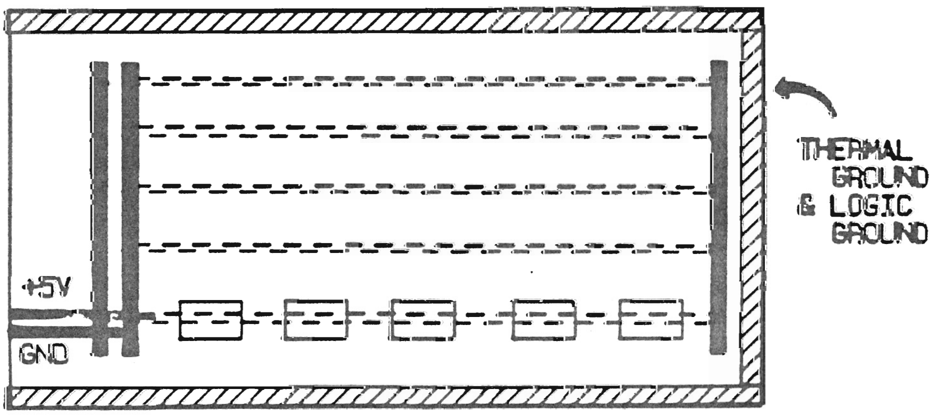
POOR PC LAYOUT

LARGE LOOP AREAS

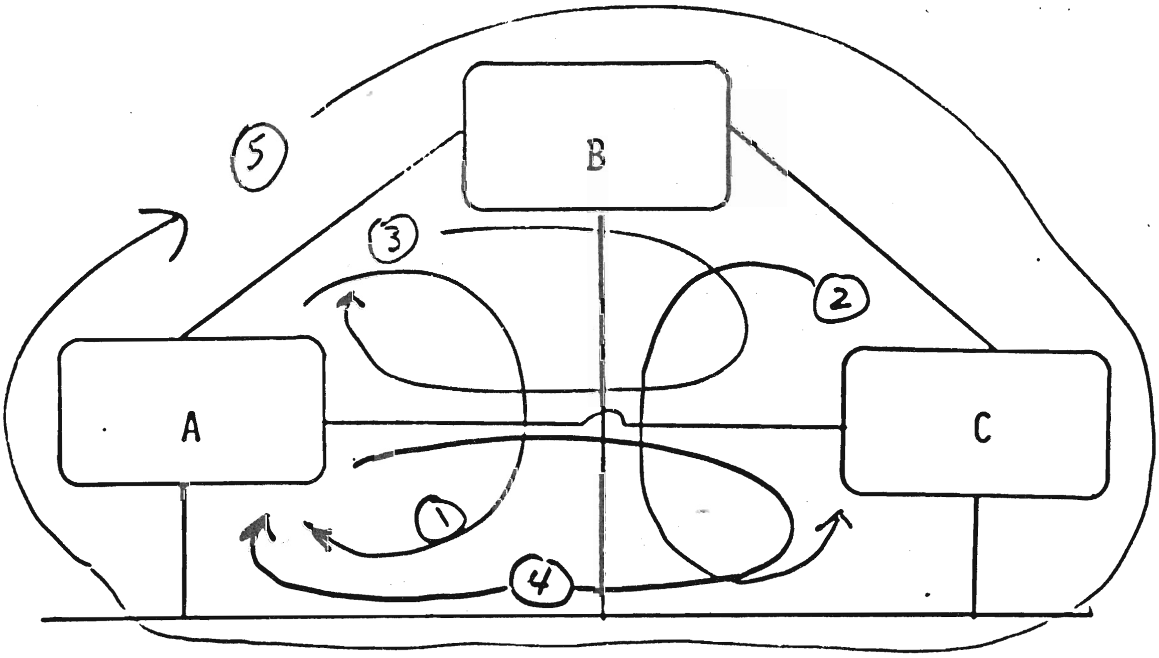


GOOD PC LAYOUT

SMALL LOOP AREAS



G R O U N D   L O O P S



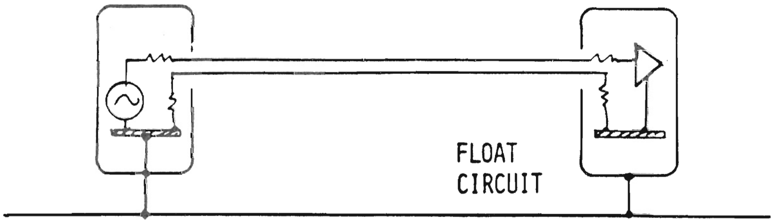
THIS SYSTEM HAS 5 LOOPS

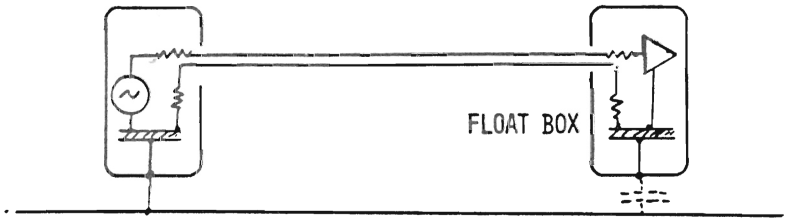
NUMBER OF LOOPS = $(N-1)^2 + (N-2)^2$

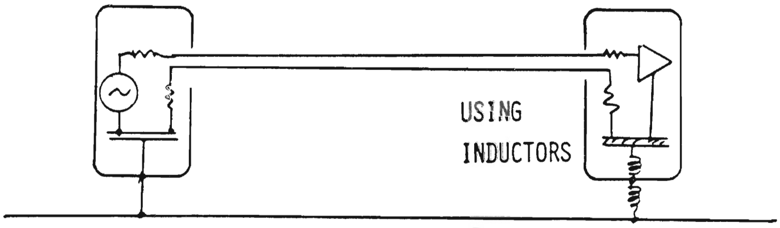
N = NUMBER OF BOXES

BOXES = 4	# LOOPS = 13
= 5	= 25
= 6	= 41

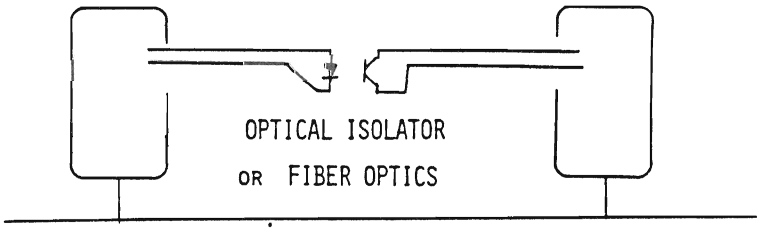
REDUCING GROUND LOOP COUPLING

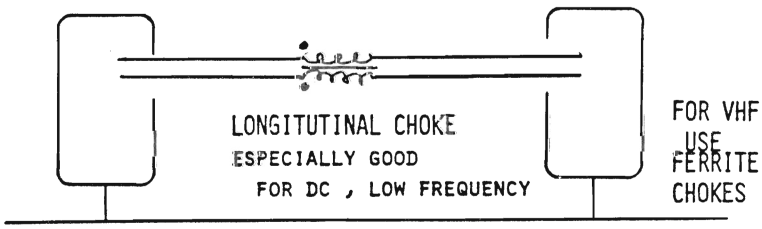


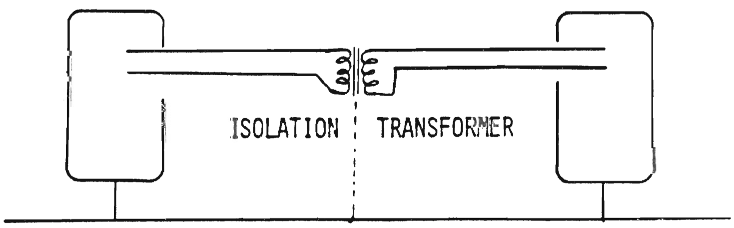




REDUCING GROUND LOOP COUPLING (CONTD)

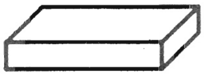






FORMULAE FOR CALCULATING IMPEDANCE OF GROUNDING MATERIALS

PLANE:

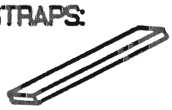


$$Z = \frac{369\sqrt{\mu_r F/\sigma_r}}{1 - e^{-T/\sigma}} \text{ MICROHMS / SQUARE}$$

WIRE:

$$R = \frac{4000\ l}{\delta \pi D} \qquad L = 787 \times 10^{-13}\ l \left[\ln\left(\frac{4\ l}{D}\right) - .75 \right]$$

STRAPS:



$$R = \frac{1000\ l}{\sigma W T} \qquad L = 2 \times 10^{-10}\ l \left[\ln \frac{2l}{W + T} + .5 + \frac{W + T}{9l} \right]$$

μ = Permeability / copper

σ = Conductivity / copper

T = Thickness, mm

D = Diameter, mm

F = Frequency, MHz

δ = Skin depth

l = Length, mm

W = Width, mm

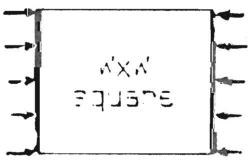
EMIS40 11/13/85

94

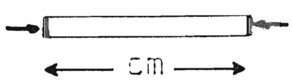
IMPEDANCE OF GROUNDING MATERIAL

	GROUND PLANES τ = 1mm			COPPER		
	STEEL	ALUM	COPPER	STRAP 10x0.3 mm	WIRE .06mm dia.	PC TRACE 1x0.03 mm
10 Hz	160µ	41µ	25µ	57µ	530µ	5.7m
10 kHz	1.3m	68µ	47µ	160µ	680µ	5.8m
100 kHz	4m	151µ	120µ	1.6m	4.3m	7.2m
1 mHz	13m	500µ	370µ	16m	43m	44m
10 mHz	40m	1.5m	1.2m	160m	430m	440m
100 mHz	130m	5m	3.7m	1.6	4.3	4.4
1 gHz	400m	15m	12m	16	43	44

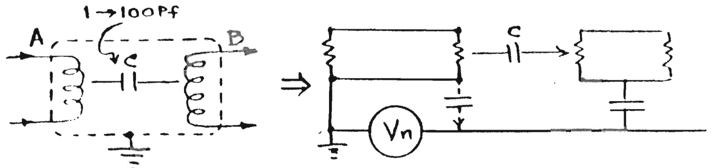
ohms/square



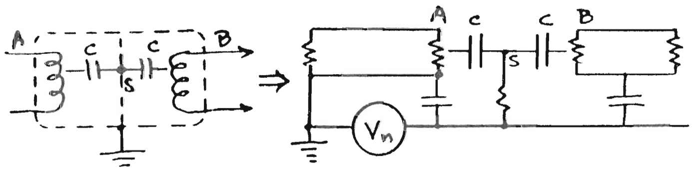
ohms/cm



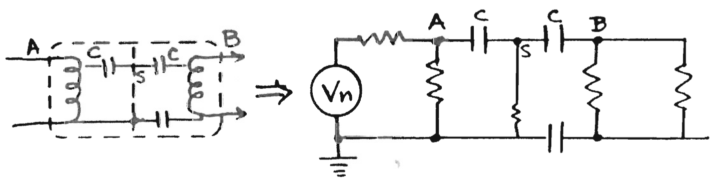
GROUNDING OF ISOLATION TRANSFORMERS



ORDINARY TRANSFORMER: CM NOISE COUPLED TO SECONDARY

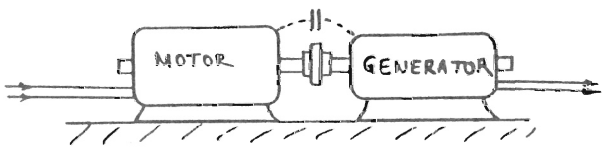


SINGLE SHIELD XFORMER: CM NOISE BYPASSED BY SHIELD



SINGLE SHIELD XFORMER: DM NOISE BYPASSED BY SHIELD

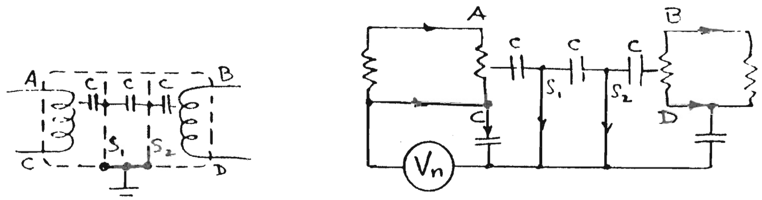
ISOLATION BY MOTOR-GENERATOR



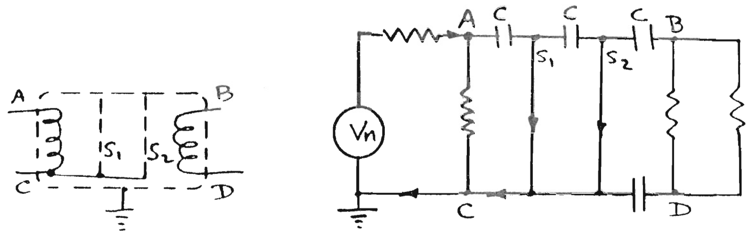
POWER INPUT:
115v 50 / 60 Hz

POWER OUTPUT:
12v 400Hz

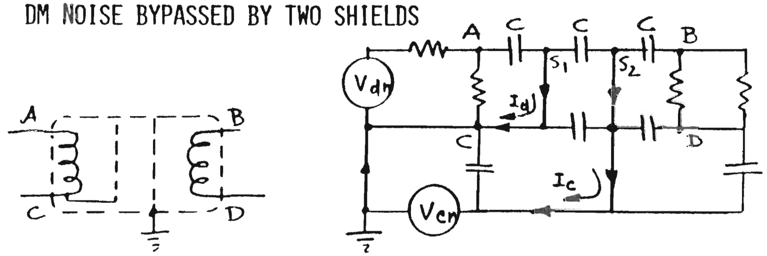
TWO SHIELD ISOLATION TRANSFORMER



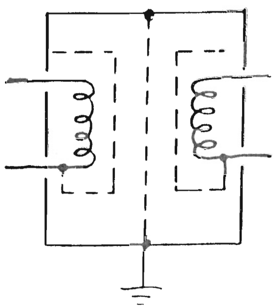
CM NOISE BYPASSED BY TWO SHIELDS



DM NOISE BYPASSED BY TWO SHIELDS



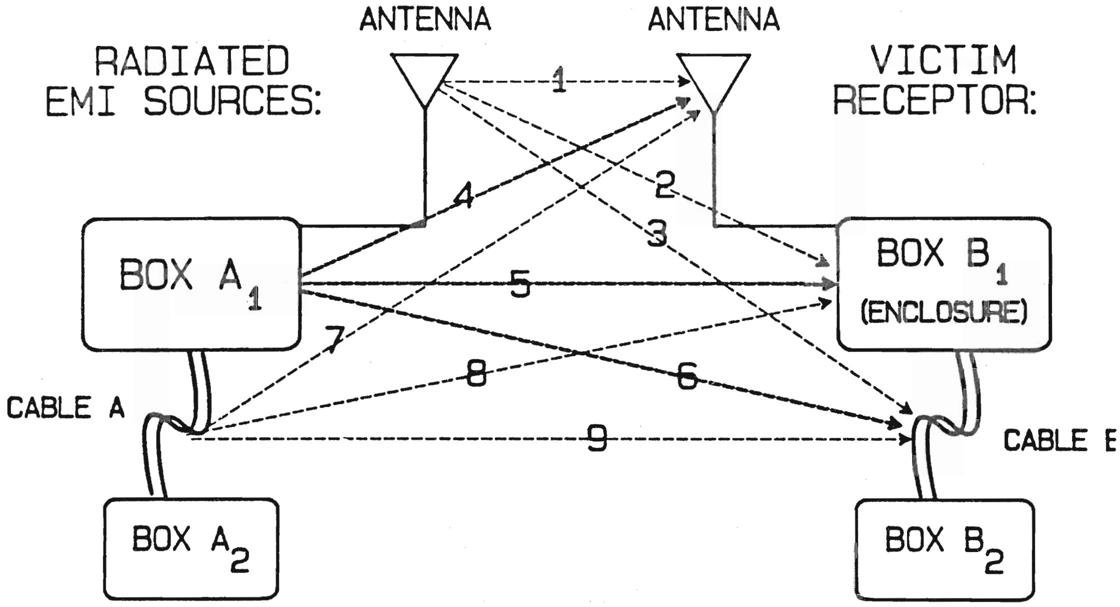
CM & DM NOISE BYPASSED BY TWO SHIELDS



TRIPLE SHIELDED
TRANSFORMER

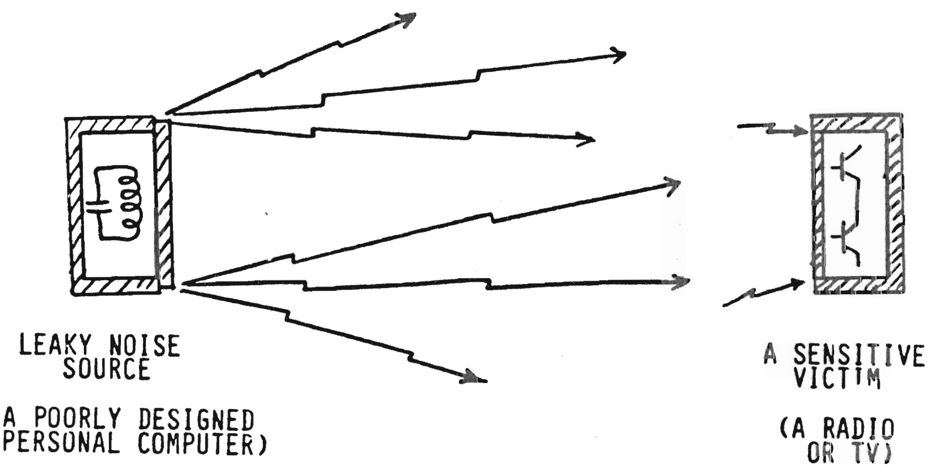
TYPICAL PRICES: ZENTEK, SAN MARCOS, CA
VDE 0550 CERTIFIED ISOLATION TRANSFORMERS

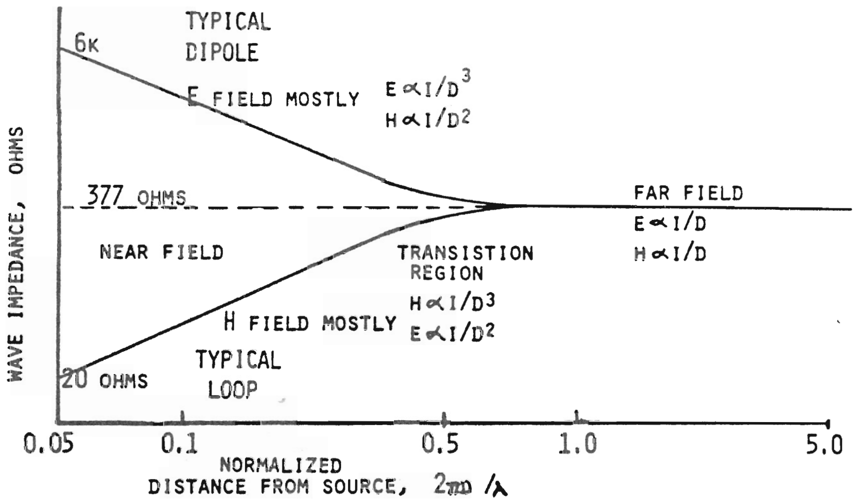
	C=.001PF	C=.0001PF
1 KVA:	$349	$399
2.5 KVA:	$479	$579
5 KVA:	$649	$749



PRINCIPLE EMI COUPLING PATHS

SHIELDING TECHNIQUES & MATERIALS



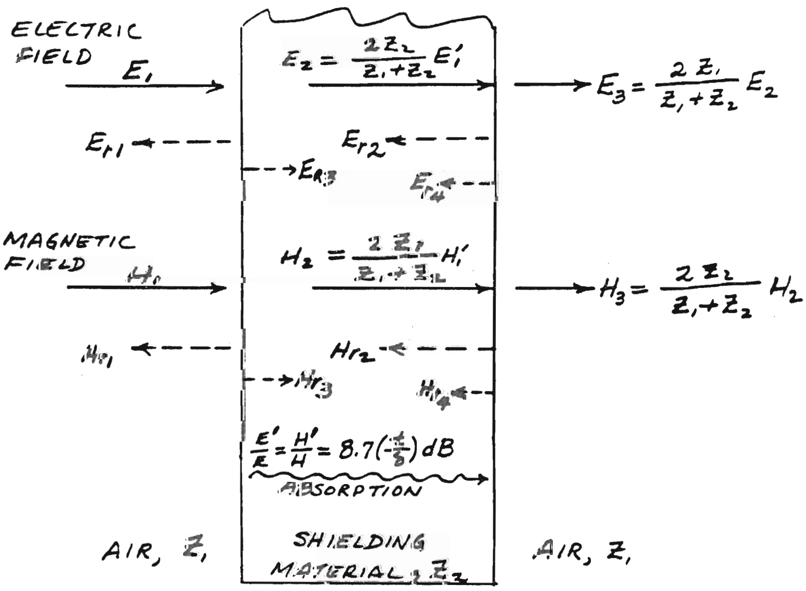


SOURCE DEPENDENT MEDIUM DEPENDENT

EXAMPLE: Frequency	= 100kHz,	Wavelength	= 3000M
	= 1 MHz		= 300M
	= 10 MHz		= 30M
	= 100MHz		= 3M
	= 1 GHz		= 30CM

SHIELDING

SHIELDING EFFECTIVENESS = { ABSORPTION LOSS + REFLECTION LOSS + MULTIPLE REFLECTION LOSS



CHARACTERISTIC IMPEDANCE OF MATERIALS

$$Z = \sqrt{\frac{j\omega\mu}{0 + j\omega\epsilon}}$$

μ = PERMEABILITY
σ = CONDUCTIVITY
ϵ = DIELECTRIC CONSTANT

MOST INSULATORS: $0 << j\omega\epsilon$

$$Z = \sqrt{\mu/\epsilon}$$

MOST CONDUCTORS: $0 >> j\omega\epsilon$

$$|Z| = \sqrt{\frac{\omega\mu}{\epsilon}} = 3.7 \times 10^{-7}\sqrt{\frac{\mu_r}{\sigma_r} f}$$

FOR AIR OR VACUUM: $Z = 377\Omega$

FOR COPPER: $Z = 1.17 \times 10^{-5}$ @ 1 KHz

$Z_A / Z_C = 3.22 \times 10^{7}$ @ 1 KHz

SILVER, AG	σ_r = 1.05	μ_r = 1.0
COPPER, CU	1.00	1.0
GOLD, AU	.70	1.0
ALUMINUM, AL	.61	1.0
BRASS	.26	1.0
STEEL, SAE1045	.10	1000.0

FREQUENCY	Zs, ALUMINUM	Zs, COPPER
1 KHz	1.5×10^{-5}	1.17×10^{-5}
10 KHz	4.74×10^{-5}	3.7×10^{-5}
100 KHz	1.5×10^{-4}	1.17×10^{-4}
1 MHz	4.74×10^{-4}	3.7×10^{-4}
10 MHz	1.5×10^{-3}	1.17×10^{-3}
100 MHz	4.74×10^{-3}	3.7×10^{-3}
1 GHz	1.5×10^{-2}	1.17×10^{-2}

REFLECTION LOSS

$$E_2 = \frac{2Z_2}{Z_1 + Z_2} E_1 \qquad H_2 = \frac{2Z_1}{Z_1 + Z_2} H_1$$

$$E_3 = \frac{2Z_1}{Z_1 + Z_2} E_2 \qquad H_3 = \frac{2Z_2}{Z_1 + Z_2} H_2$$

$$E_3 = \frac{4Z_1Z_2}{(Z_1 + Z_2)^2} E_1 \qquad H_3 = \frac{4Z_1Z_2}{(Z_1 + Z_2)^2} H_1$$

WHEN $Z_1 >> Z_2$

$$E_3 = \frac{4Z_2}{Z_1} E_1 \qquad H_3 = \frac{4Z_2}{Z_1} H_0$$

$$R = 20 \log \frac{|Z_1|}{4|Z_2|}, \text{ dB}$$

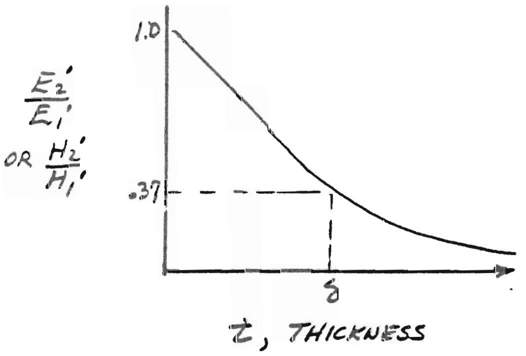
FOR AIR → COPPER → AIR (FOR FAR FIELD)

$$R = 20 \log \frac{Z_a}{4Z_s} = 138 \text{ dB at 1 KHz}$$

FOR GENERAL CASE:

$$R = 20 \log \frac{94}{|Z_2|} = 168 - 10 \log(\mu_r f/\sigma_r) \text{ dB}$$

ABSORPTION LOSS



$$E_2' = E_1' e^{-t/\delta}$$

$$H_2' = H_2' e^{-t/\delta}$$

δ = SKIN DEPTH

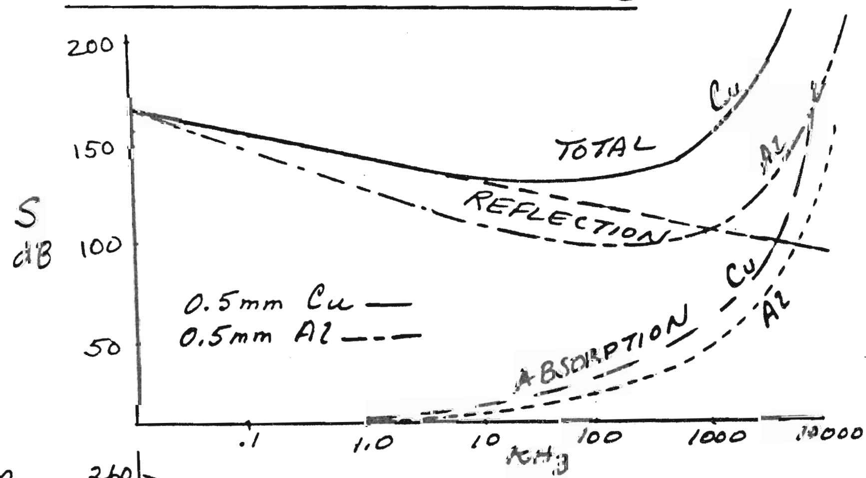
$$A = 20\left(\frac{t}{\delta}\right) \log e \quad = 8.69 \frac{t}{\delta} \ dB$$

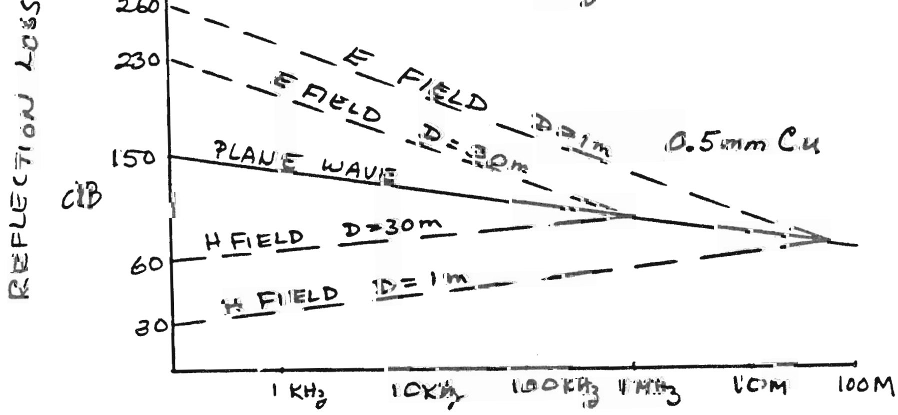
OR $\quad A = 1.31\, t \sqrt{f \mu_r \sigma_r} \quad dB$

t, CM

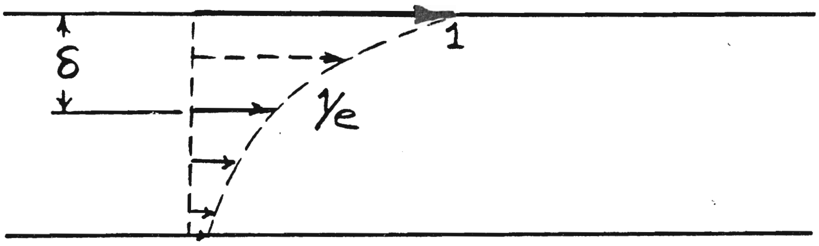
(LOSS TANGENT $\triangleq \frac{j\omega\epsilon}{\sigma}$)

SHIELDING EFFECTIVENESS





SKIN DEPTH



$$\delta = \left(\frac{\lambda}{\pi \sigma \mu c}\right)^{1/2} \text{ (meters)} \qquad \lambda = \frac{c}{f}$$

$$\sigma = .5731 \times 10^{8} \sigma_r \qquad \sigma_r = \frac{\sigma_x}{\sigma_{cu}} = \frac{\rho_{cu}}{\rho_x}$$

$$\mu = 4\pi \times 10^{-7} \mu_r \qquad \mu_r = \frac{\mu_x}{\mu_{cu}} = \frac{\mu_{cu}}{\mu_x}$$

$$\delta = \frac{.0665}{\sqrt{f \sigma_r \mu_r}} \text{ (meters)} = \frac{66.5}{\sqrt{f \sigma_r \mu_r}} \text{ (mm)}$$

where $f \Rightarrow$ Hertz

$\sigma_r \Rightarrow$ Relative conductivity to copper

$\mu_r \Rightarrow$ Relative permeability to copper

then:

$$\delta = \frac{66.5}{\sqrt{f}} \text{ (mm)} \quad \text{for copper}$$

$$= \frac{85}{\sqrt{f}} \text{ (mm)} \quad \text{for aluminum}, \ \sigma_r = .61$$

$$= \frac{6.65}{\sqrt{f}} \text{ (mm)} \quad \text{for steel (1045)}, \ \sigma_r = 0.1, \ \mu_r = 1000$$

ELECTRICAL PROPERTIES OF METALS

Metal	Relative Conductivity	Relative Permeability (at 150 kHz)	Skin Depth (mm @ 1Hz)
Silver	1.05	1	65
Copper, annealed	1.00	1	66.5
Copper, hard drawn	0.97	1	67.5
Gold	0.70	1	79
Aluminum	0.61	1	85
Magnesium	0.38	1	108
Zinc	0.29	1	123
Brass	0.26	1	130
Nickel	0.20	1	148
Phosphor-bronze	0.18	1	157
Iron	0.17	1000	5.1
Tin	0.15	1	171
Steel, SAW 1045	0.10	1000	6.6
Beryllium	0.10	1	210
Lead	0.08	1	235
Hypernick	0.06	80000	0.96
Monel	0.04	1	333
Nu-Metal	0.03	80000	1.36
Permalloy	0.03	80000	1.36
Stainless steel	0.02	1000	14.9

SKIN DEPTH = (mm @ 1Hz)/$\sqrt{f}$

SKIN DEPTH OF COMMON MATERIALS (mm)

FREQ	Cu	Al	Steel	MuMetal
60 Hz	8.5	10.9	0.86	0.36
120 Hz	4.3	5.5	0.43	0.18
1 kHz	2.1	2.7	0.20	0.09
10 kHz	0.66	0.84	0.08	0.03
100 kHz	0.21	0.27	0.02	0.009
1 mHz	0.07	0.08	0.008	—
10 mHz	0.02	0.03	0.002	—
100 mHz	0.007	0.008	0.0008	—

REDUCTION OF EMI FROM AND TO ENCLOSURES

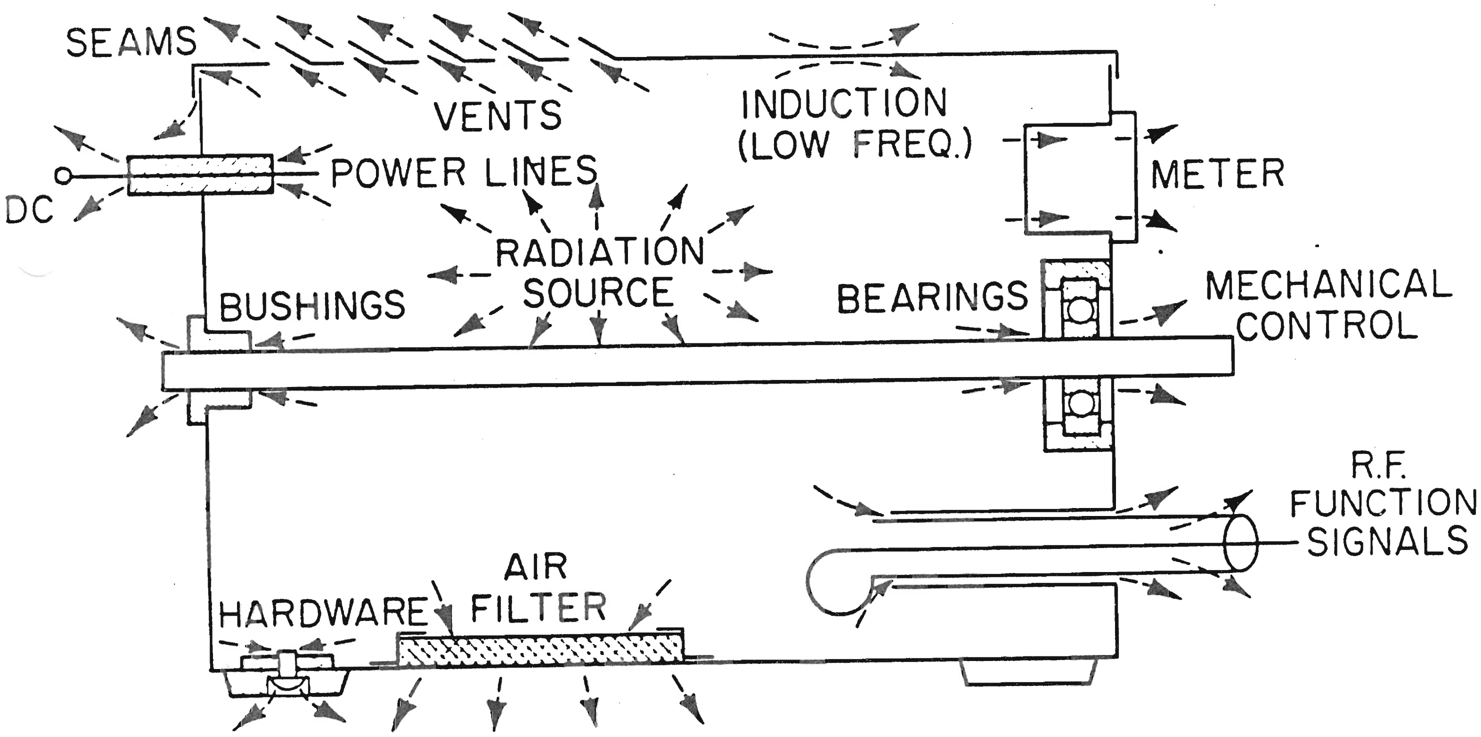
INTERFERENCE ---------- SUSCEPTIBILITY

LOCATIONS OF EMI LEAKAGE:

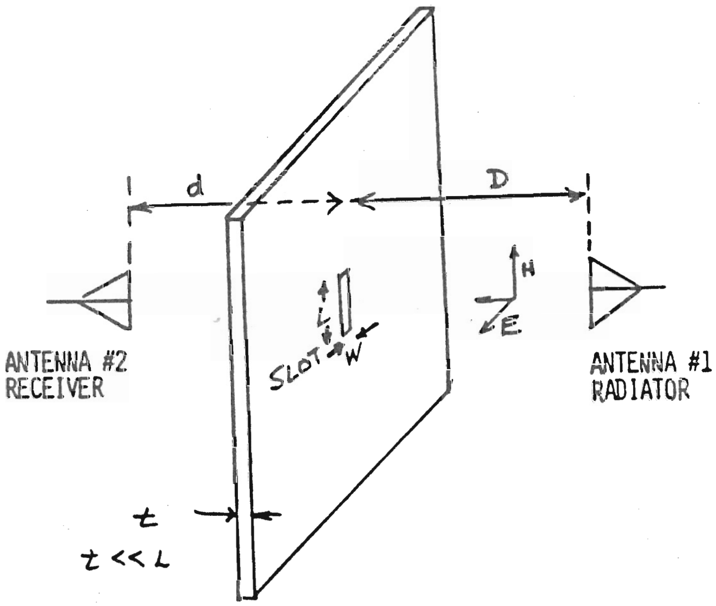
- o WALLS OF ENCLOSURES, ESPECIALLY LOW FREQUENCY
- o SEAMS AND JOINTS
- o HOLES FOR VENTILATION...COOLING
- o HOLES FOR METERS, SWITCHES, POTENTIOMETERS, ETC.
- o BEARINGS AND SHAFTS
- o POWER LEADS AND CONNECTORS
- o SIGNAL INPUT AND OUTPUT LEADS

METHODS:

- o CONFINE SIGNAL ENERGY TO LOCAL AREA
- o LOCATE SIGNAL ENERGY AWAY FROM LEAKAGE PATHS
- o CONDUCT SIGNAL ENERGY AWAY FROM LEAKAGE PATHS
- o REFLECT SIGNAL ENERGY AWAY FROM LEAKAGE PATHS
- o ABSORB SIGNAL ENERGY IN THE LEAKAGE PATHS



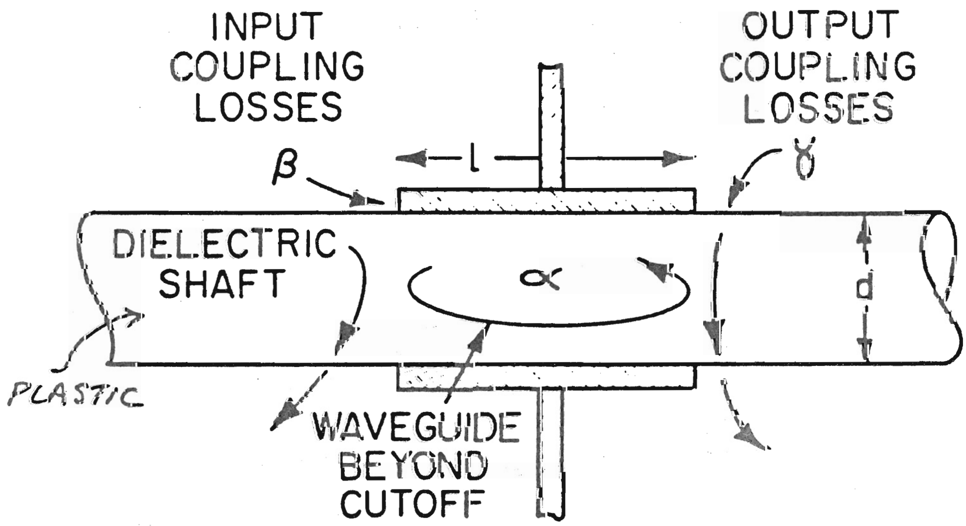
IG. 1. TYPICAL ELECTRONIC MODULE ILLUSTRATING RF LEAKAGE



A SLOT IS ENERGIZED BY POWER FROM ANTENNA #1

THE SLOT WILL RERADIATE TO ANOTHER RECEPTOR, ANTENNA #2:

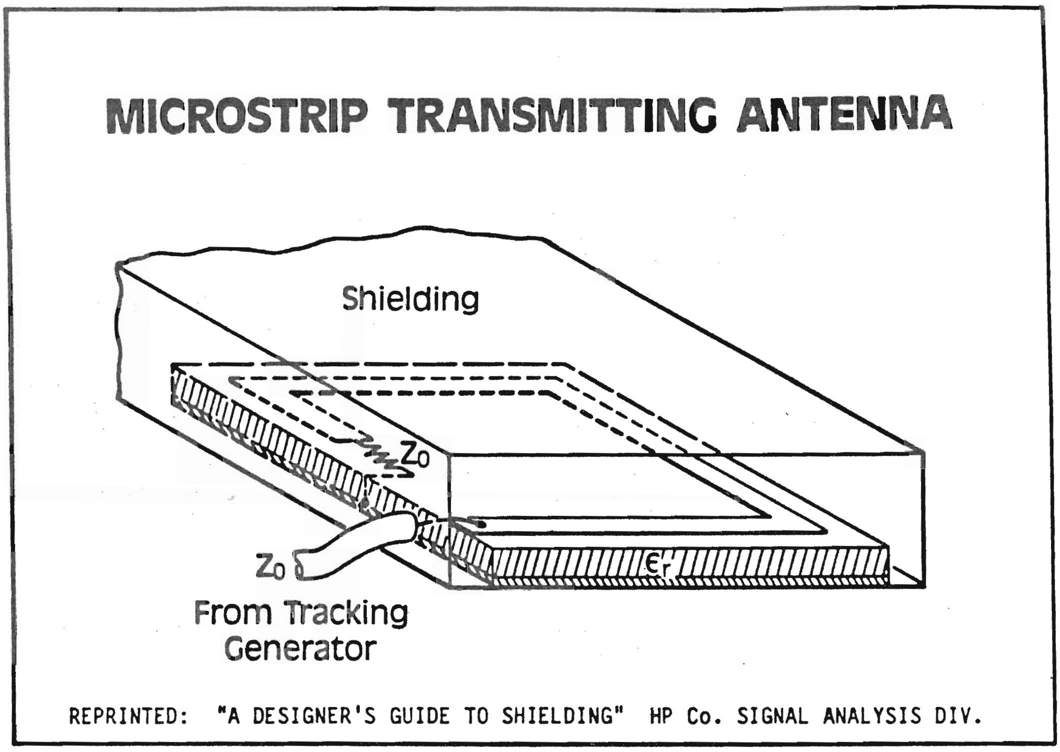
COUPLING BECOMES MAXIMUM AS SLOT LENGTH APPROACHES $\lambda/2$



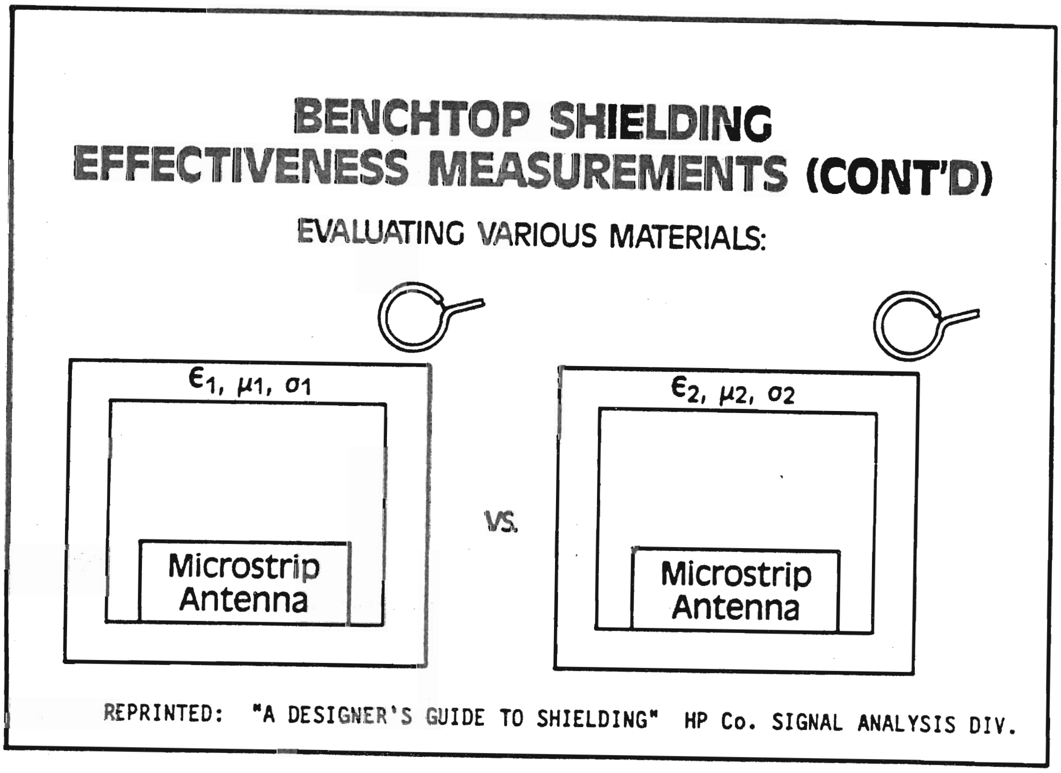
TOTAL ATTENUATION $= \beta + \alpha + \gamma$

$\alpha = (32/\sqrt{e})(l/d)$ DB

FIG. 11. ATTENUATION THROUGH A DIELECTRIC SHAFT



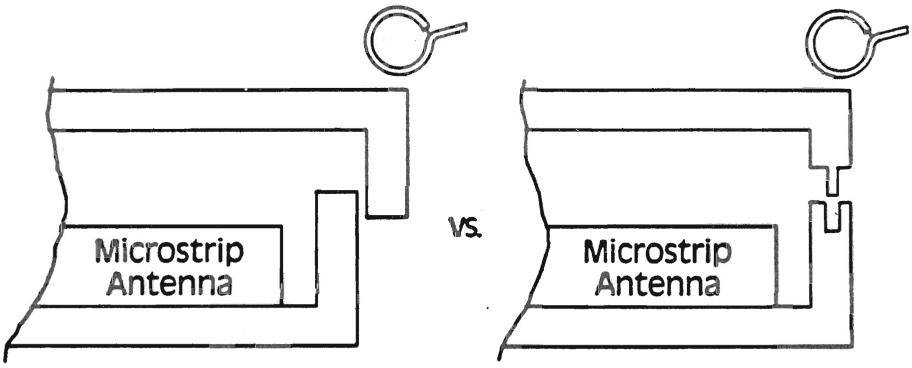
A recommended broadband transmitting structure is a 50 ohm microstrip trace terminated in its characteristic impedance. These antennas are inexpensive, easy to fabricate in a variety of shapes and maintain their input characteristics over the entire operating range of the tracking generator. Microstrip design curves are readily available; low dielectric constant material and long lengths of line maximize the radiation. Low radiation efficiency is the major tradeoff for the broadband operation. Measurement repeatability requires care in antenna placement relative to the shield in question. It is necessary to have the shield of the coaxial input connector well grounded to the shielding enclosure under test.



The shielding effectiveness of different materials relative to each other is best measured using identical geometries. This testing is especially useful for measuring the frequency dependency of the shielding effectiveness of magnetic material. Pre- and post-amplification is usually required when testing magnetic material due to the low frequency range of operation. When measuring larger enclosures, screen room or open site testing is often necessary.

BENCHTOP SHIELDING EFFECTIVENESS MEASUREMENTS

EVALUATING VARIOUS PHYSICAL CONFIGURATIONS:



- Overall effectiveness of different seam configurations
- Localized shielding discontinuities

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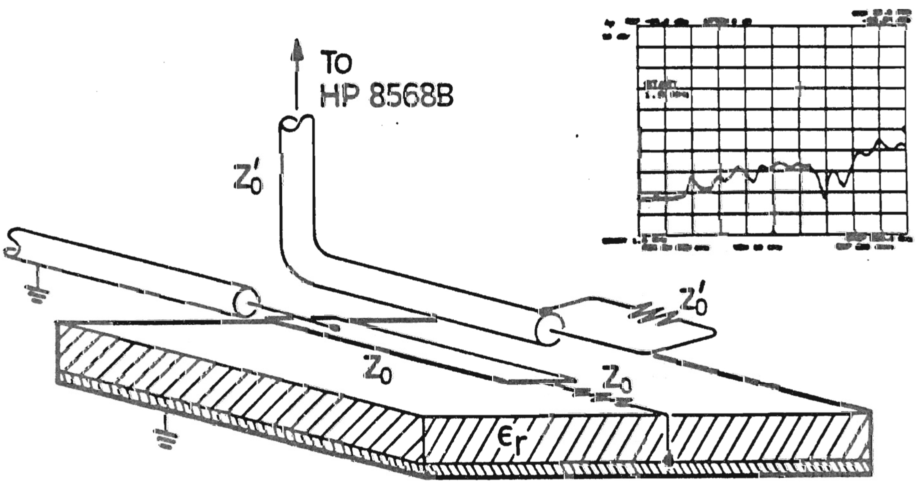
Benchtop testing provides information which is more useful for system troubleshooting than overall system shielding tests in screen rooms or on open sites. Time spent reducing the radiation from sub-systems of an instrument greatly reduces final system qualification time.

The most general type of benchtop testing performed involves characterization of the shielding effectiveness of various geometries. This includes evaluation of the design of instrument cases and individual circuit shields, seam configurations, and gasketing. Swept, benchtop measurements provide the designer with immediate feedback on shielding effectiveness; localized testing pinpoints radiation problems on an individual circuit

MEASUREMENT OF COAXIAL CABLE SHIELDING EFFECTIVENESS



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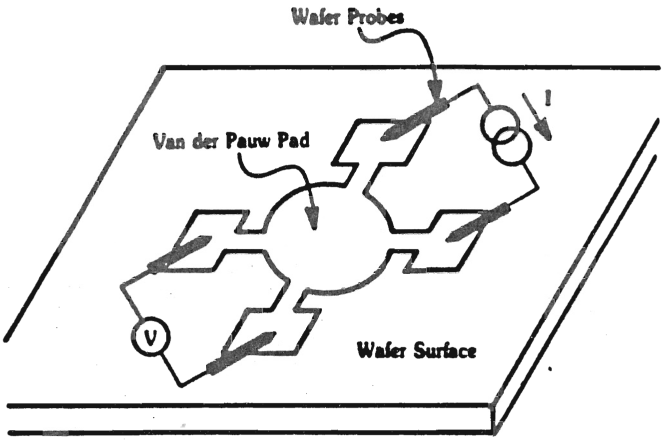
Proper cable shielding minimizes system design and troubleshooting time. Cable shielding problems are major contributors to overall system noise, cross talk between channels or systems and data transfer errors. High speed digital systems are one of the major challenges to quality cable shielding.

Benchtop cable shielding evaluation is a simple procedure with a swept measurement system. A microstrip line is used as the transmitting antenna and the cabling in question is the receiving antenna and is connected to the spectrum analyzer. The shielding effectiveness is indicated by the amount of signal coupled into the cabling. Direct comparisions between different cabling types can be made quickly.



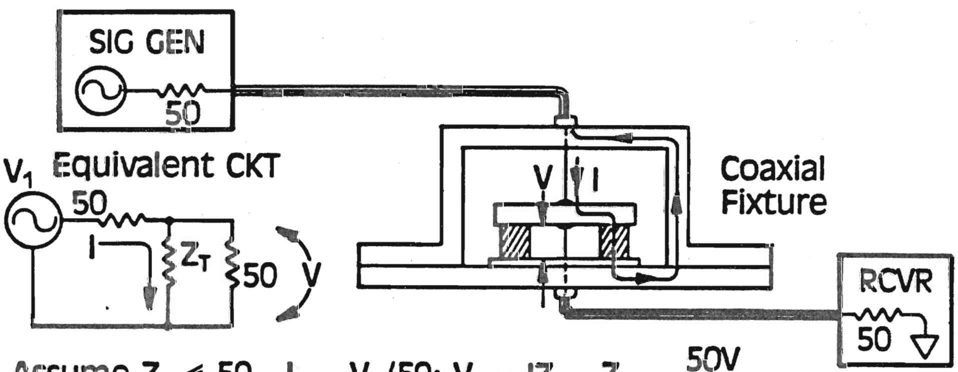
$\rho_s = 4.53 \frac{V}{I}$ = Sheet Resistance

Sheet Resistance – 2 Probes or 4 Probes

Evaluation of diffusion processes are commonly done by measuring sheet resistance using 2 probe or 4 probe method. HP's 4062A is well suited for this application using 4 versatile dc source/monitor units (SMU's). Each SMU can operate in two modes: 1) voltage source/current monitor, or 2) current source/voltage monitor. Total dc source/monitor range is ±1 picoamp to ±100 milliamps. Total voltage monitor range is ±100 microvolts to ±100 volts.

Software for measuring sheet resistance is supplied in 4062A system library. Shown here is a 4 probe method using Van der Pauw pad configuration.

MEASUREMENT OF THE TRANSFER IMPEDANCE OF A GASKET

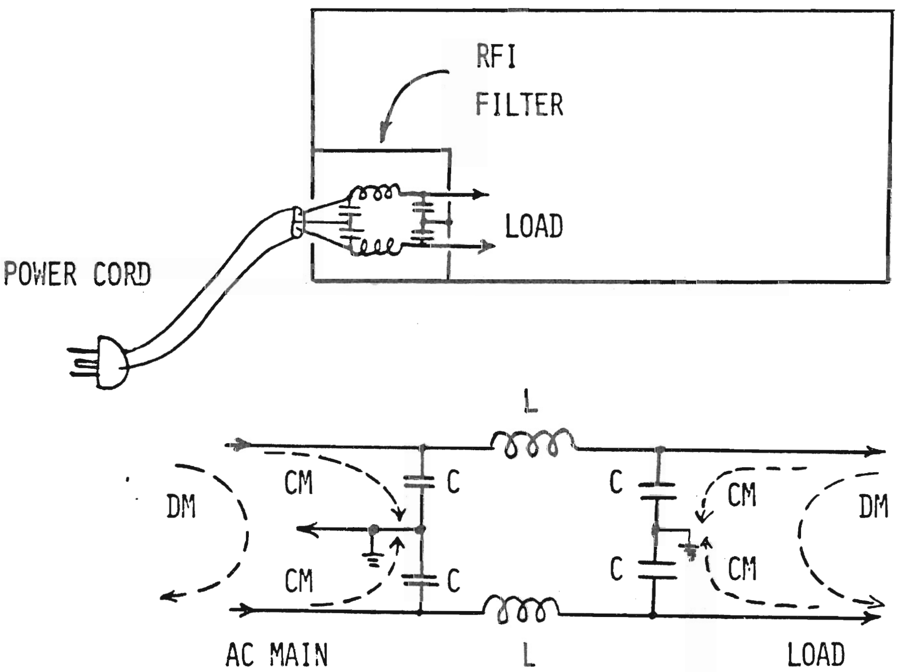


Assume $Z_T \ll 50$ $\quad I = V_1/50;\ V = IZ_T \quad Z_T = \frac{50V}{V_1}$

Transfer Impedance is Ordinarily Normalized Per Unit Length

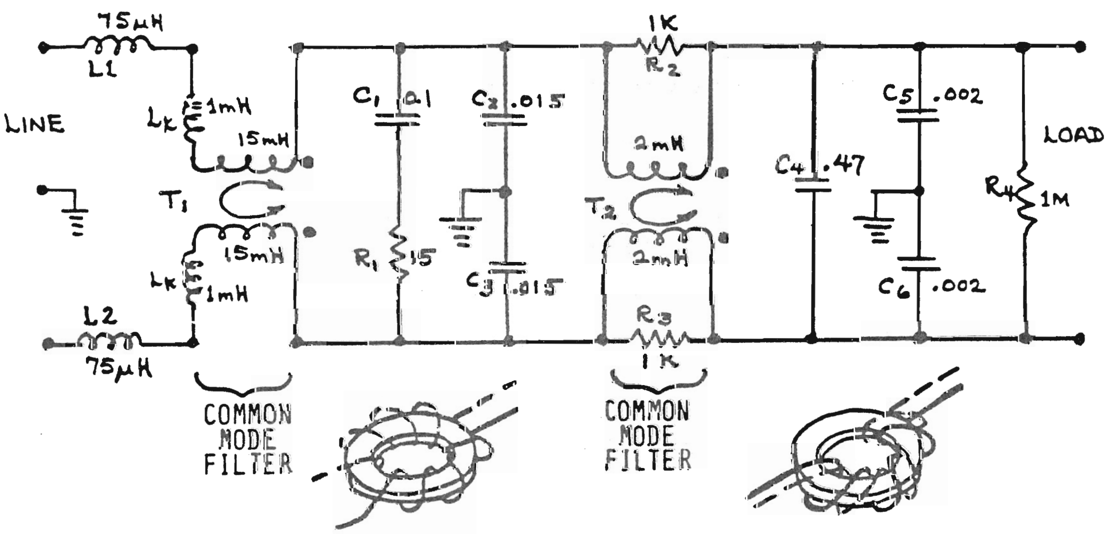
$\boxed{Z_{TR} = \frac{Z_T}{\ell}}$; Where ℓ = Perimeter of Gasket

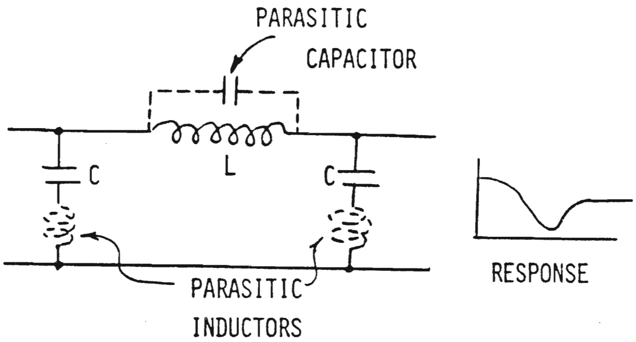
RFI FILTERS IN ENCLOSURES

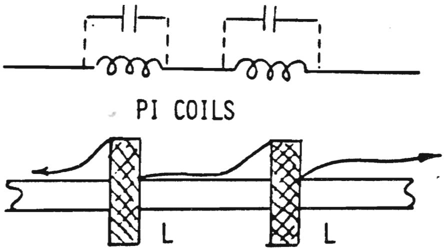


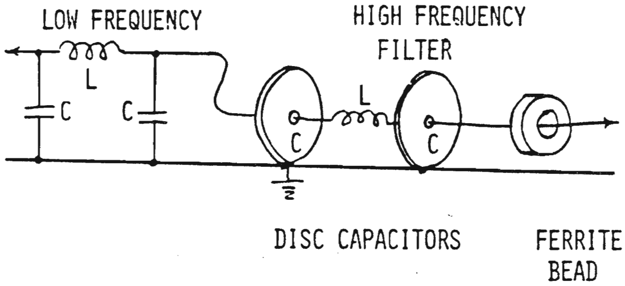
POWER LINE FILTER HP 9135-0134

FOR SWITCHING POWER SUPPLY



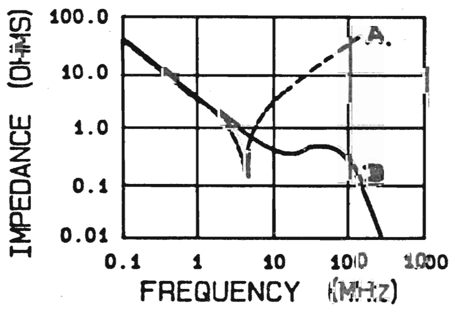




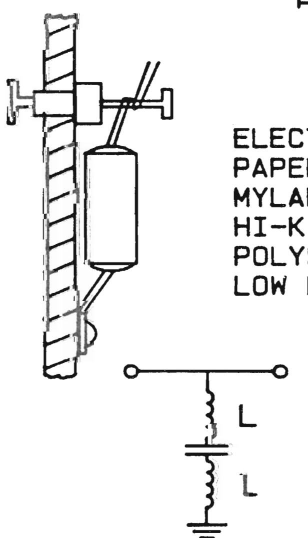


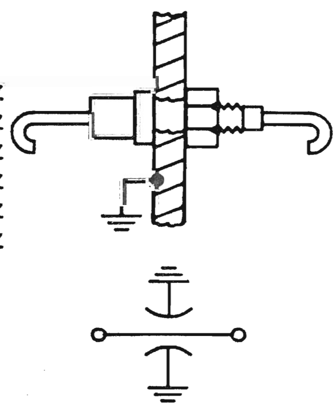
RESONANCE IN CAPACITORS

A. 0.05 µF
CAPACITOR WITH
6mm LEADS



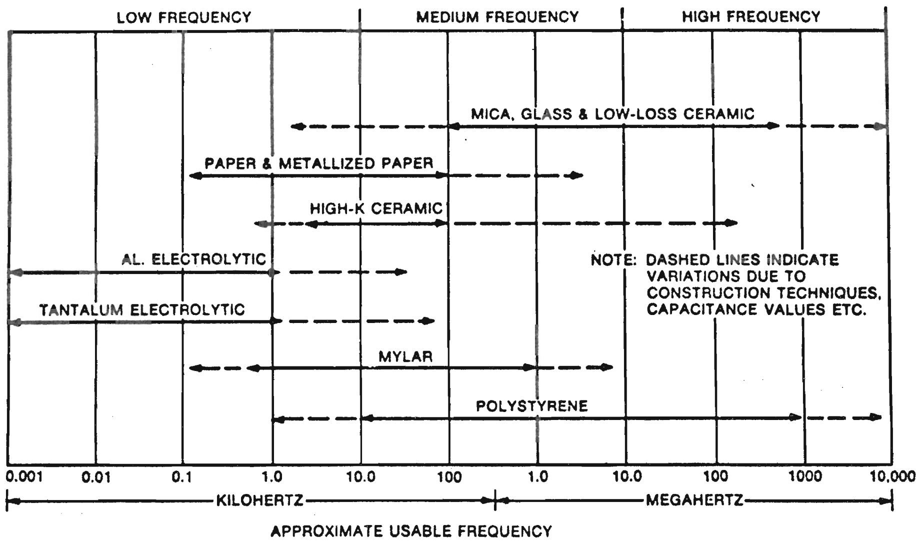
B. 0.05 µF
FEED-THROUGH
CAPACITOR





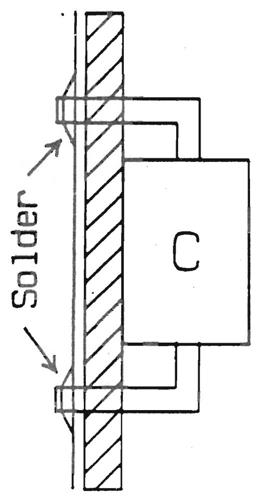
ELECTROLYTICS, AL OR Ta	1-50kHz
PAPERS	0.1 - 10mHz
MYLARS	1-10mHz
HI-K CERAMICS	0.1-200mHz
POLYSTYRENE, MICA	500mHz-10GHz
LOW LOSS CERAMICS	500mHz-10GHz

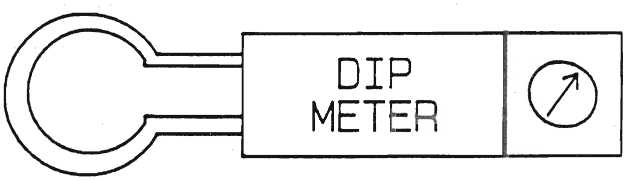
APPROXIMATE USABLE FREQUENCY RANGES FOR VARIOUS TYPES OF CAPACITORS

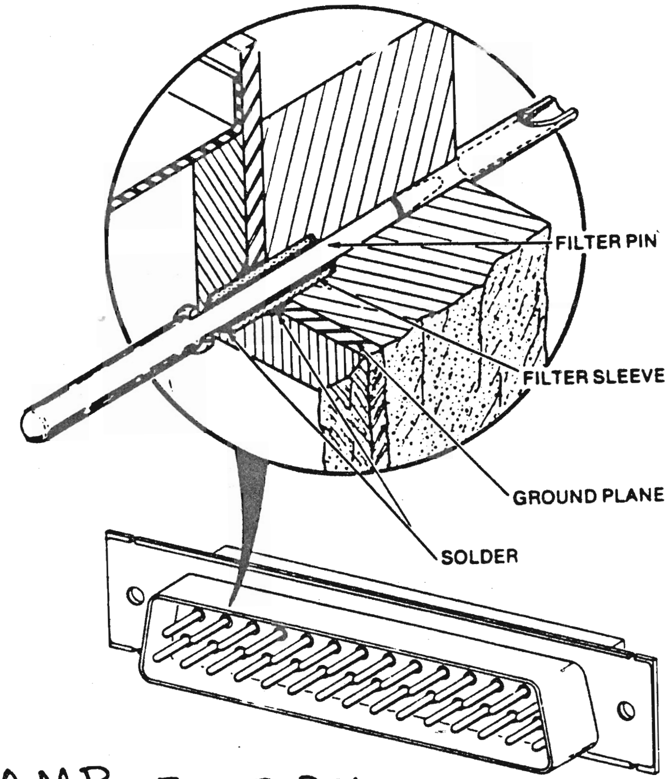


TYPICAL RESONANCE FREQUENCY OF CERAMIC CAPACITORS WITH 6mm LEADS

100 nf	2.5 mHz
10 nf	12
1 nf	35
500 pf	70
100 pf	150
50 pf	220
10 pf	500





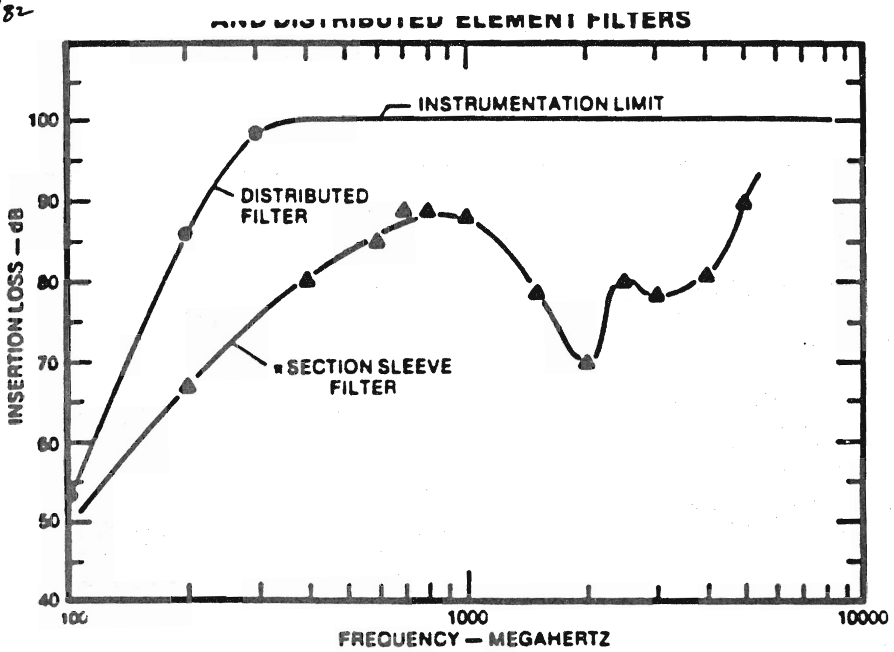


AMP - FILTER PIN CONNECTOR

CANNON

Fig. 3

3/82



AMP - FILTER PIN CONNECTOR

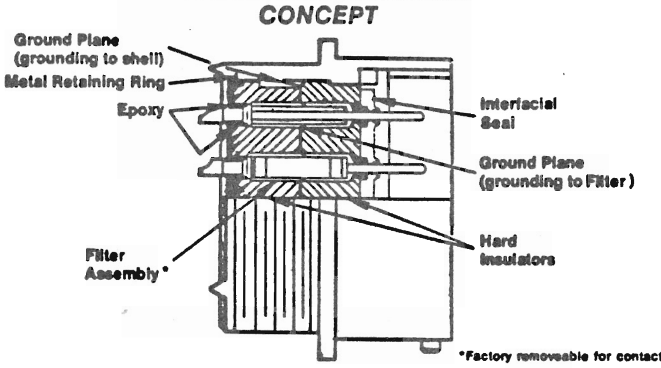
CANNON

Fig. 2

3/82

CANNON
ITT

TYPICAL CONSTRUCTION CONCEPT



*Factory removeable for contact repair/replacement.

Types of Contacts
Three types of contacts are available for each contact position: *filter* contacts, *power* contacts that use an insulating tube instead of the filter element, or *grounded* contacts. These contacts can be intermixed in any arrangement to offer maximum circuit flexibility at reduced costs.

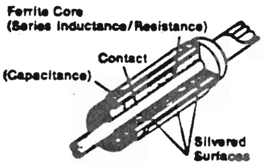
Operating Temperatures
Filter contacts are designed to operate within the temperature ranges of −55°C to +125°C without any significant changes in insertion loss characteristics. They will also operate at temperatures up to +150°C with temporary performance reduction. At +150°C there is a reduction of approximately 15% insertion loss at 100 MHz and over.

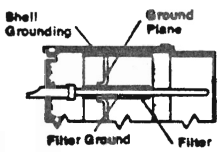
Repairability
Under most circumstances filter connectors are repairable at the factory, and new product "re-warranty" is provided.

Insertion Loss vs. Current
Insertion loss characteristics will vary slightly, depending on the amount of current flowing through the contacts. However, this loss is not significant; as insertion losses in the stop band from 100 MHz and over are still above minimums when the specified maximum current rating is not exceeded.

Intermateability with Standard Product Lines
All ITT Cannon Filter Connectors have the same layout pattern and contact spacing as their equivalent non-filtered connectors, and are intermateable and intermountable with them. The basic difference is that they are solder termination while some of the non-filtered versions may be crimp. Also, all rear accessories are ordered separately.

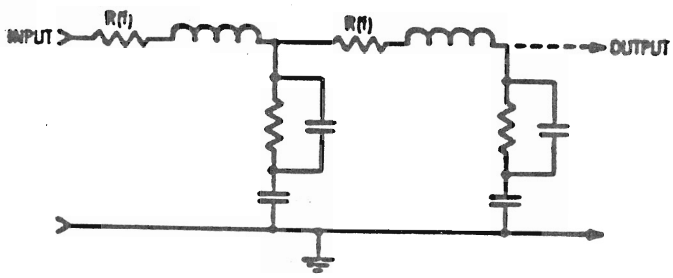
Filter Operation

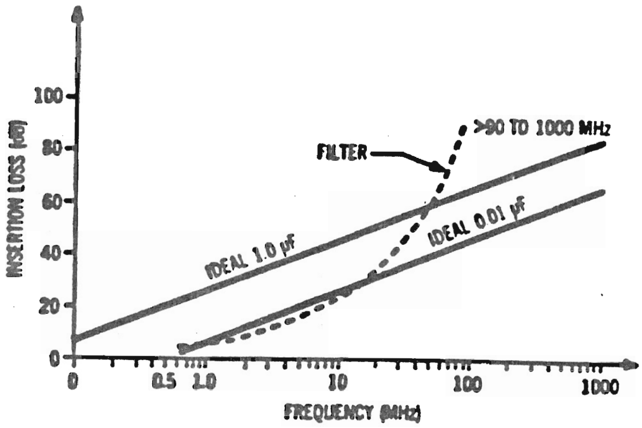


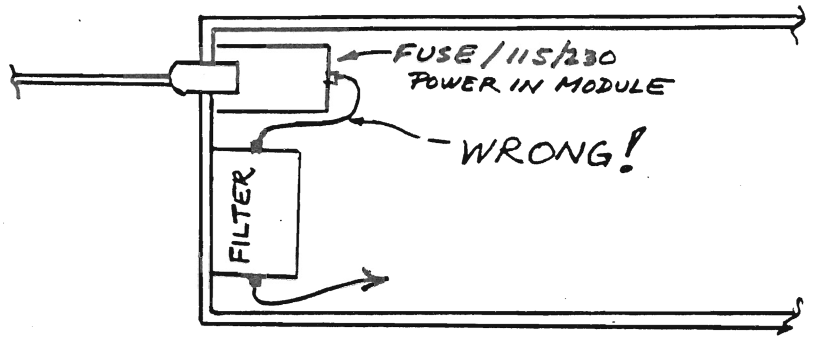


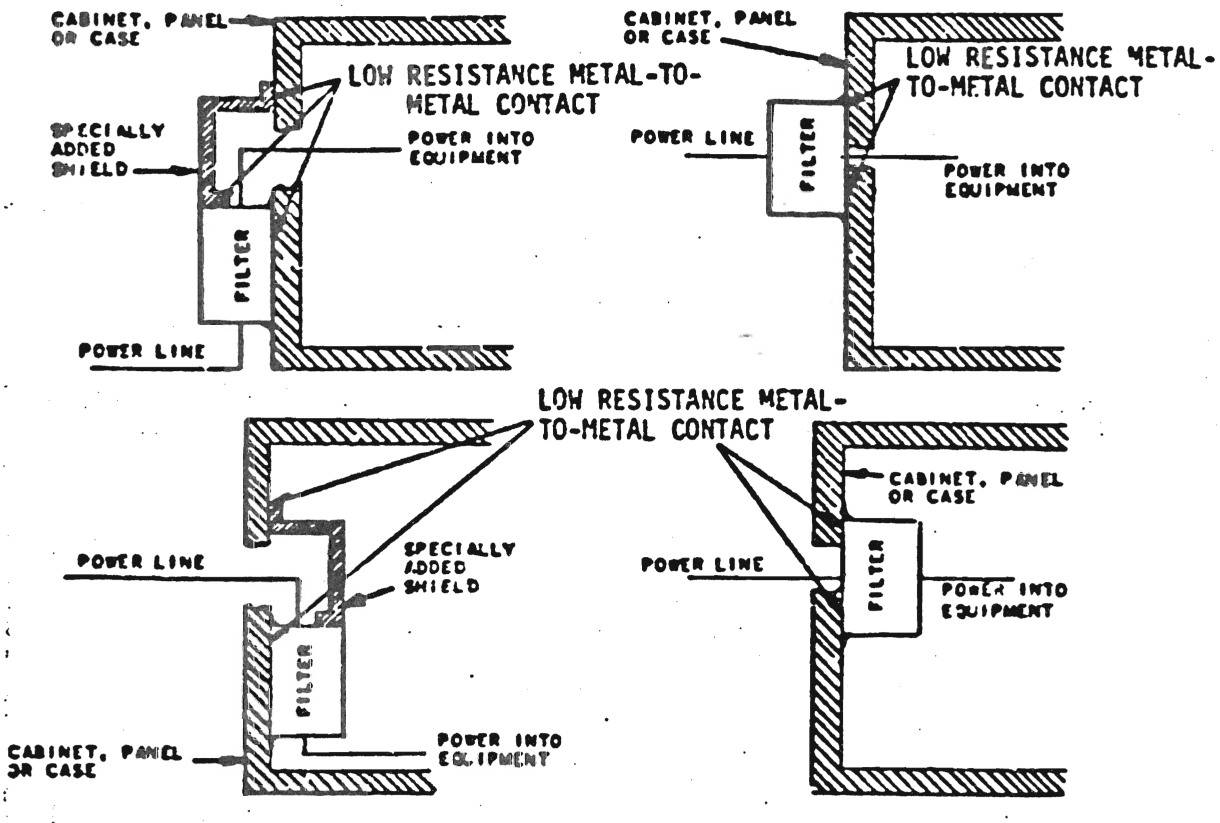
Concept
Without altering the normal function of a standard connector contact, the filter contact provides RFI suppression at frequencies above a prescribed point (low pass). Through the use of special ceramic and ferrite compounds, shaped, plated and located appropriately, a network approximating a Pi-section low-pass filter is achieved on any or all contacts on a standard connector.

Design
A high-permeability ferrite tube surrounds the contact forming the equivalent series inductor (may be thought of as a one turn toroid). The shunt capacitor members appear as a result of selective plating of a high dielectric constant ceramic tube. Both ends of this ceramic tube, which concentrically envelopes the ferrite, are affixed to the contact to form an extremely compact circuit. The plated O.D. of the ceramic tube is the common electrode and is attached to the shell through a ground plane. In addition to this interconnection of filter to shell, the ground plane forms an "electric wall" preventing alternate paths for radiated RFI, a frequent problem in discrete filter circuits at higher frequencies.

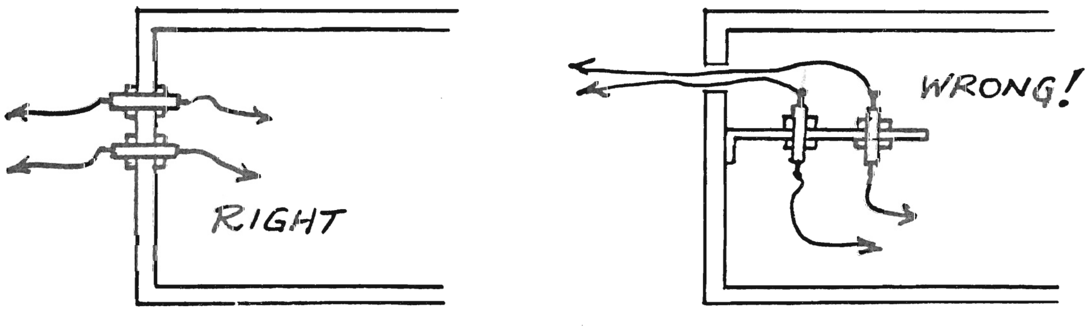






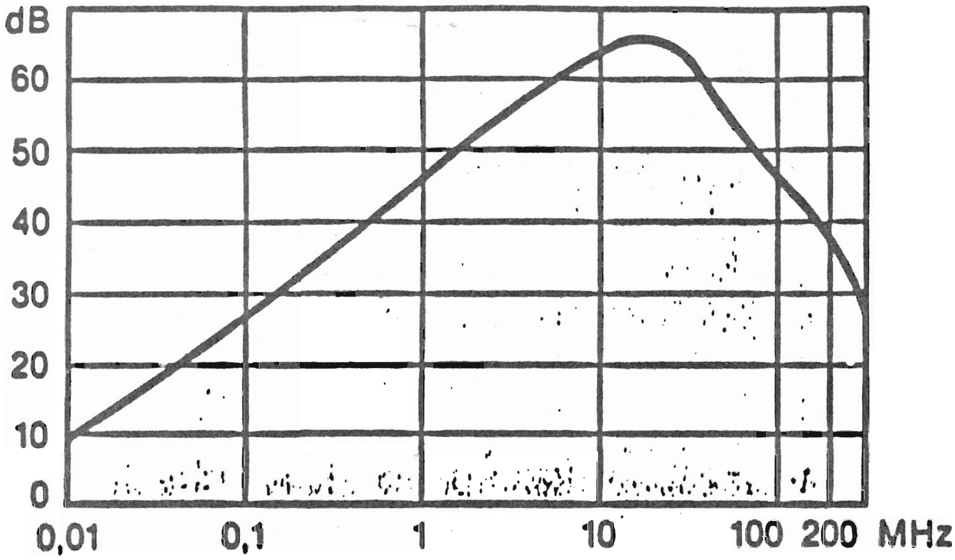


CORRECT Installation of Power Line Filters

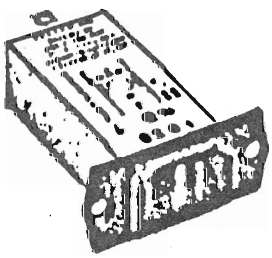


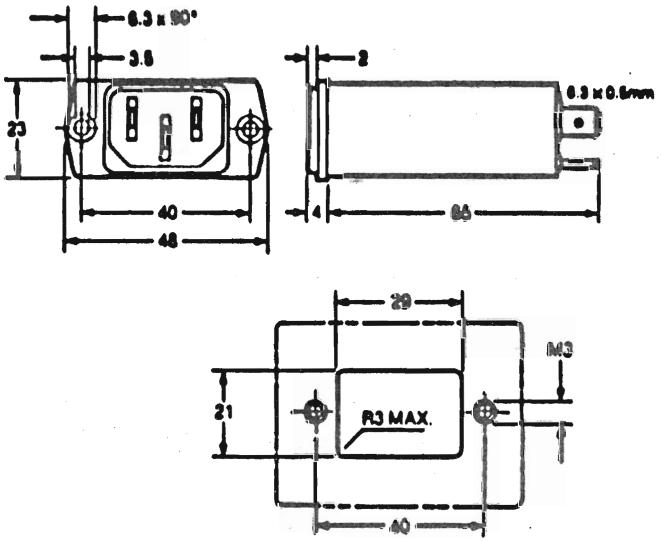
INSTALLATION OF FEEDTHRU CAPACITORS

4 AMP

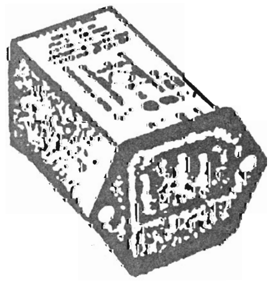


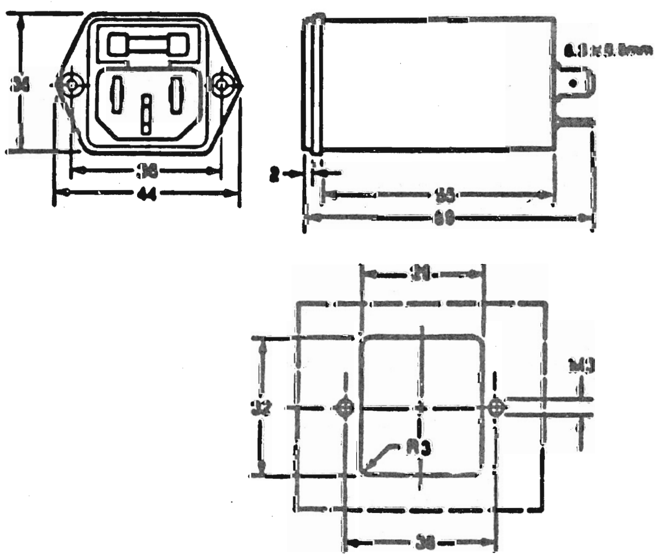
Integral CEE-22 & International power line filter





Integral fused CEE-22 connector & International power line filter





EMC/EMI TESTING

NEEDS:

- SIMULATED ENVIRONMENT WHERE USED
- REPEATABLE MEASUREMENTS
- MEETS SPECIFICATIONS

EMC/EMI TESTING

SITE FOR TESTING:

* IDEAL PLACE HAS NO OTHER RADIATION OR REFLECTION
  - ISOLATED FIELD
  - SHIELDED ROOM
  - ANECHOIC ROOM (ABSORBING MATERIAL ON WALLS)
  - NATURAL CAVE (ABSORBING MATERIAL ON WALLS)
  - MODE STIRRED SHIELDED ROOM
  - STRIPLINE TESTER
  - TEM CELL TESTER

EMC/EMI TESTING

ELECTRONIC TEST EQUIPMENT:

- SIGNAL SOURCES, HIGH POWER NECESSARY
- DETECTORS:
  * EMI RECEIVERS (SPECIAL FILTERS, DETECTOR RC TIME CONSTANT)
  * SPECTRUM ANALYZERS

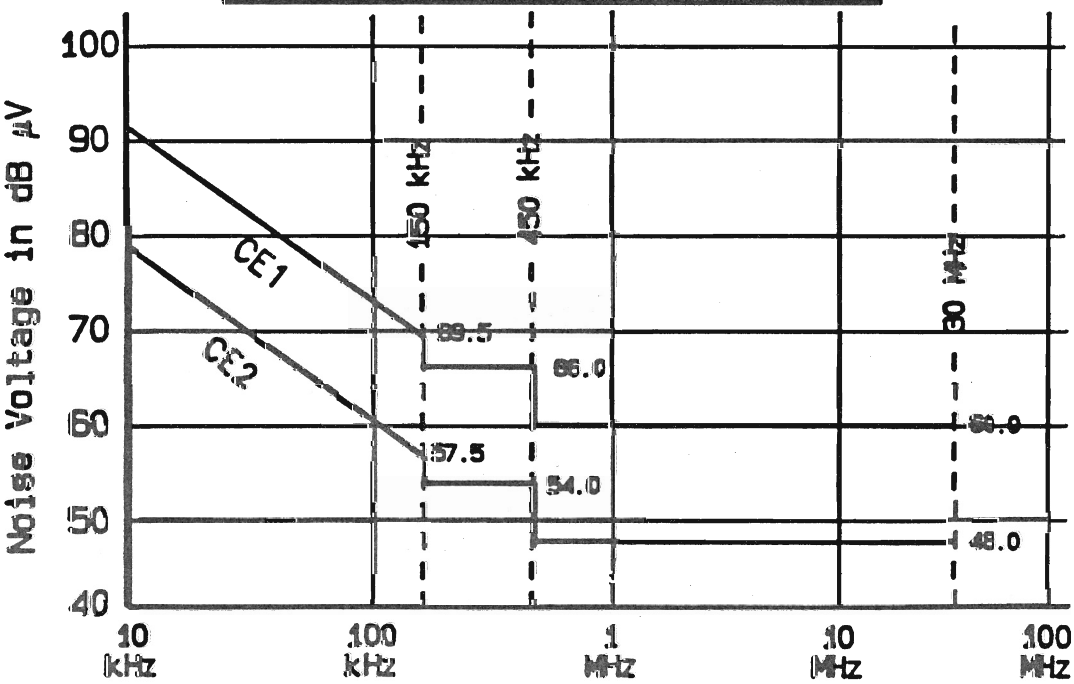
HEWLETT PACKARD
ENVIRONMENTAL SPECIFICATIONS

CONDUCTED EMISSION LIMITS

3 LEVELS SPECIFIED

CE1 CORRESPONDS TO:
10kHz TO 30MHz - VDE 0871 LEVEL A,
CISPR PUB. 11, 1979
450kHz TO 30MHz - FCC PART 15 J, CLASS A
CE2 CORRESPONDS TO:
10kHz TO 30MHz - VDE 0871 LEVEL B
450kHz TO 30MHz - FCC PART 15 J, CLASS B
CE3 CORRESPONDS TO:
FTZ 526

HEWLETT PACKARD
ENVIRONMENTAL SPECIFICATIONS



Conducted Emission Limits for CE1 and CE2

HEWLETT PACKARD
ENVIRONMENTAL SPECIFICATIONS

RADIATED EMISSION LIMITS

3 LEVELS SPECIFIED

RE1 - MAXIMUM ALLOWABLE FOR ANY HP PRODUCT

RE2 - PREFERRED MAXIMUM ALLOWABLE FOR ANY HP PRODUCT; MORE STRINGENT, REQUIRED IN MANY HP MARKETS

RE3 - MAXIMUM ALLOWABLE FOR ANY HP PRODUCT MARKETED IN USA FOR RESIDENTIAL USE

HEWLETT PACKARD
ENVIRONMENTAL SPECIFICATIONS

RADIATED EMISSION LIMITS

RE1 CORRESPONDS TO THE MOST RESTRICTIVE OF CISPR PUB. 11, FCC PART 15J CLASS A, AND VDE 0871 LEVEL A

FREQUENCY MHz	LIMIT dB (μV/m)	ANTENNA DISTANCE (METERS)
0.01-30	32	100m
30-88	28	30m
88-174	32	30m
174-230	28	30m
230-1000	35	30m

HEWLETT PACKARD
ENVIRONMENTAL SPECIFICATIONS

RADIATED EMISSION LIMITS

RE2 CORRESPONDS TO THE MOST RESTRICTIVE
OF VDE 0871 LEVEL B AND FTZ 1046

FREQUENCY MHz	LIMIT dB (µV/m)	ANTENNA DISTANCE (METERS)
0.01-30	32	30m
30-470	32	10m
470-1000	38	10m

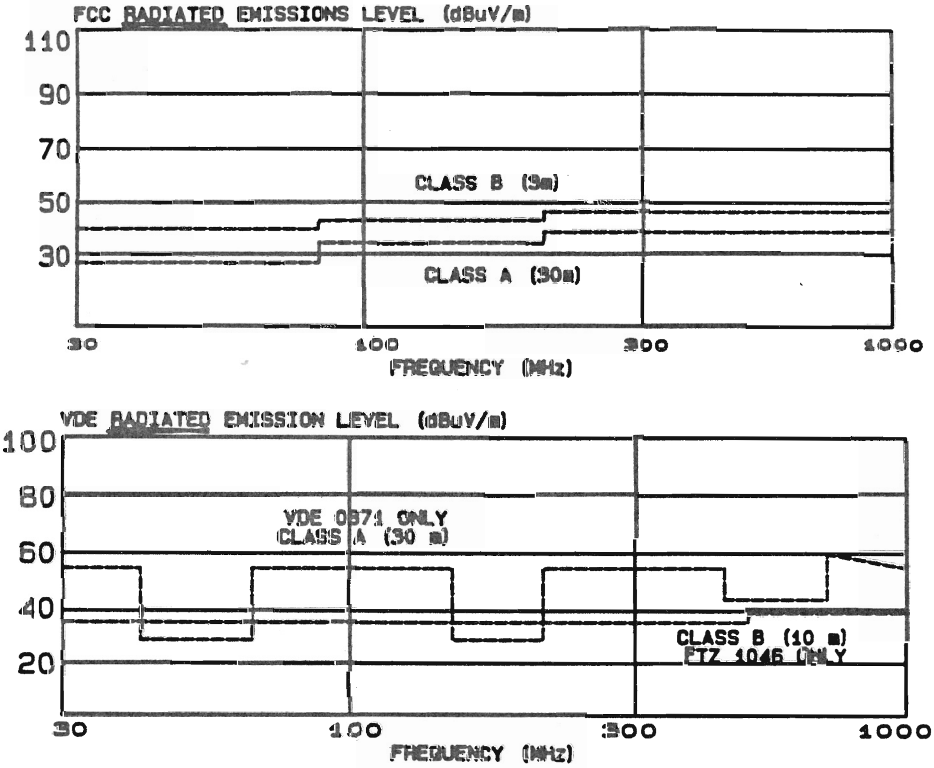
HEWLETT PACKARD
ENVIRONMENTAL SPECIFICATIONS

RADIATED EMISSION LIMITS

RE3 CORRESPONDS TO FCC PART 15 J CLASS B

FREQUENCY MHz	LIMIT dB (µV/m)	ANTENNA DISTANCE (METERS)
30-88	40	3m
88-216	44	3m
216-1000	46	3m

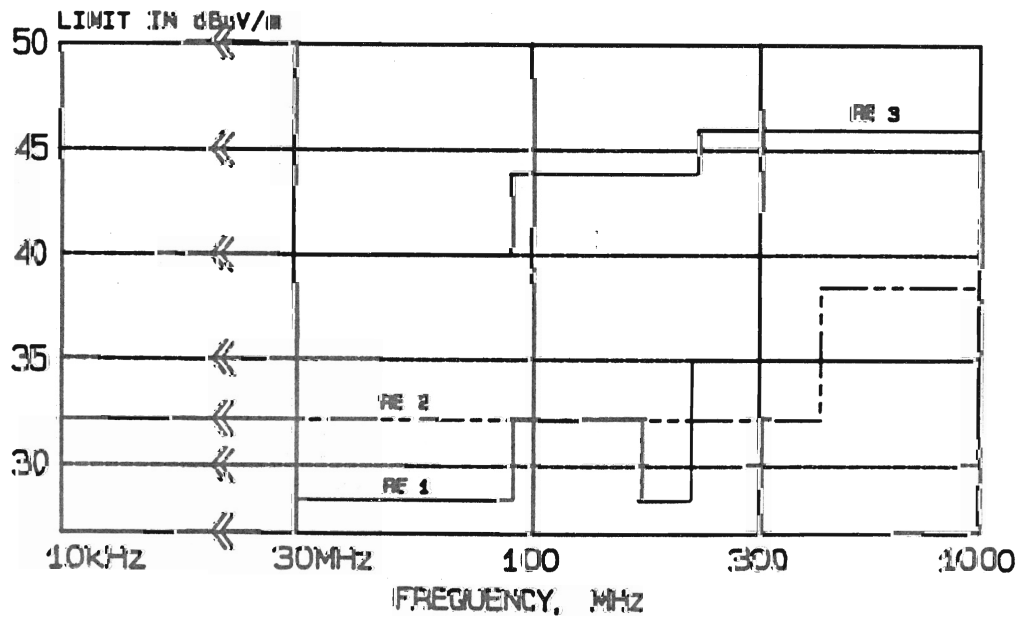
RADIATED EMISSION LIMITS



EMIS26A/B 10/1/85

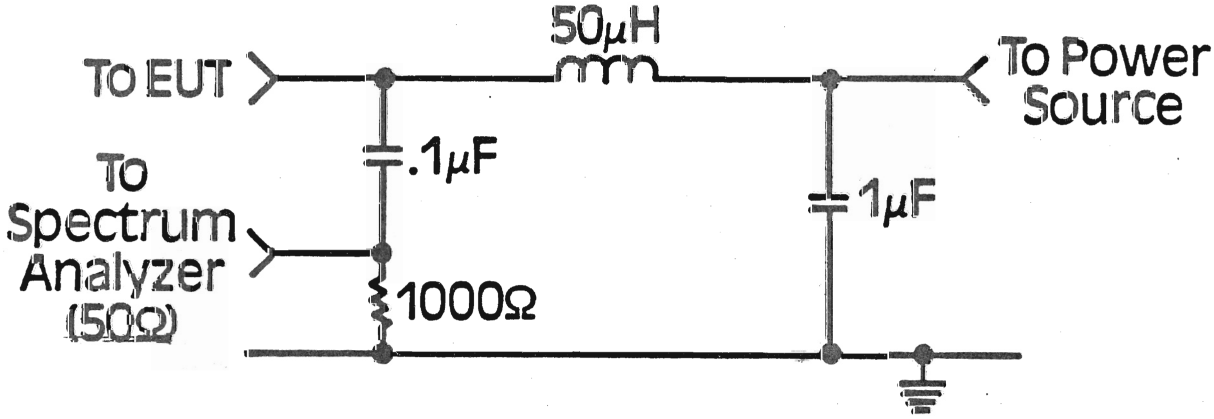
HP RADIATION EMISSION LIMITS

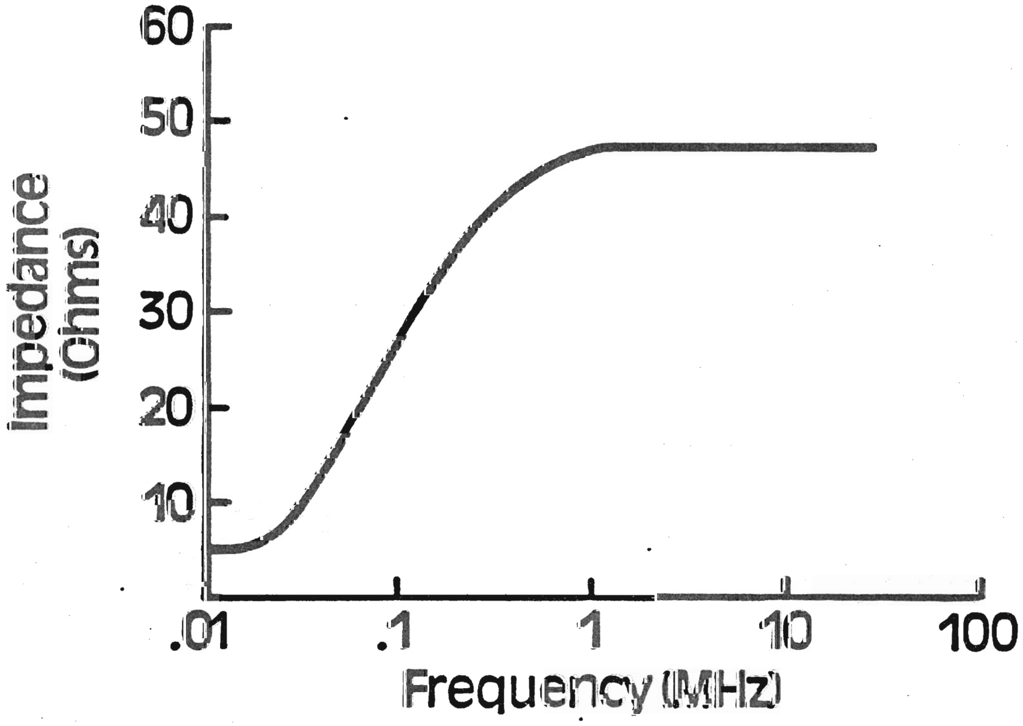
RE1 (100m, .01-30 MHz; 30m, 30-1000 MHz)
RE2 (30m, .01-30 MHz; 10m, 30-1000 MHz)
RE3 (3m, 30-1000 MHz)



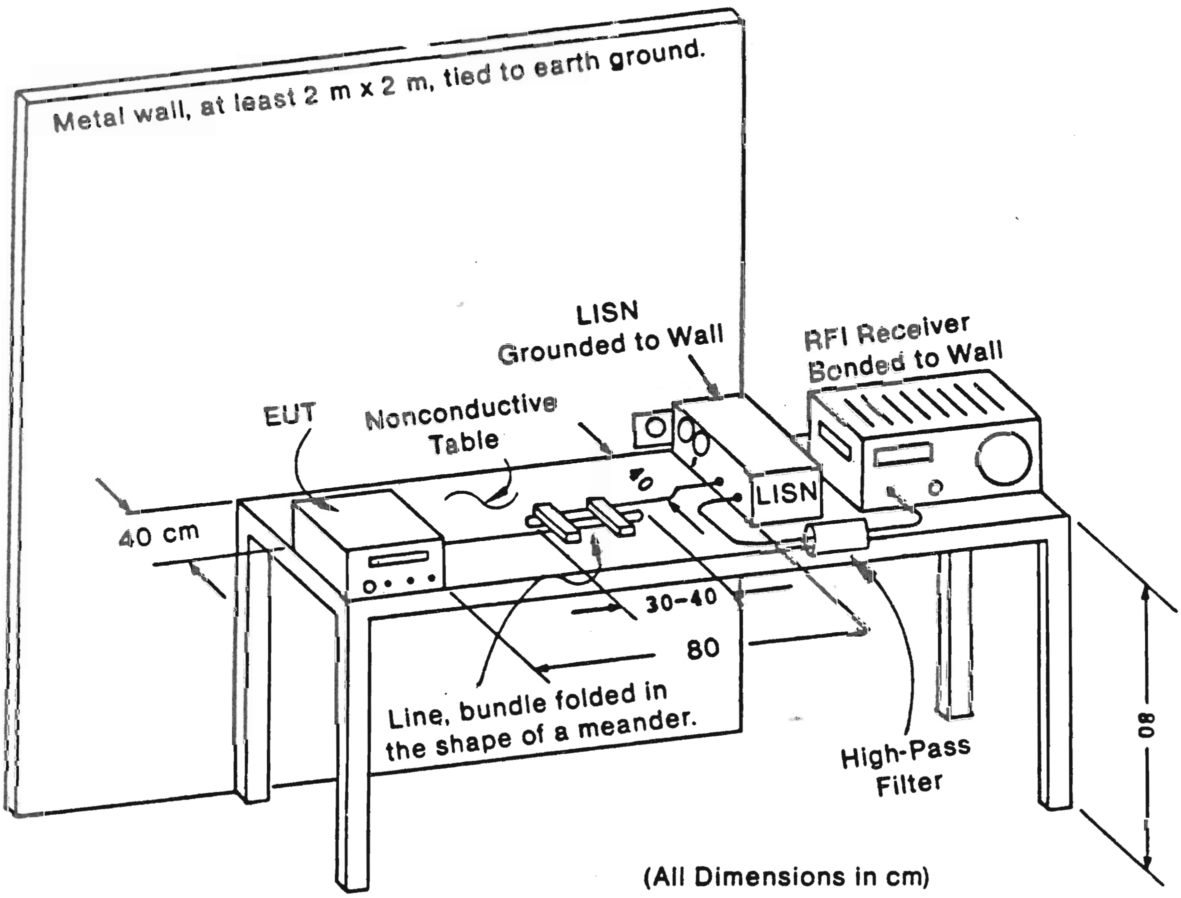
EMIS2a 10/1/85

LINE IMPEDANCE STABILIZATION NETWORKS FILTER OUTSIDE EMISSIONS AND PROVIDE A DEFINED LINE IMPEDANCE

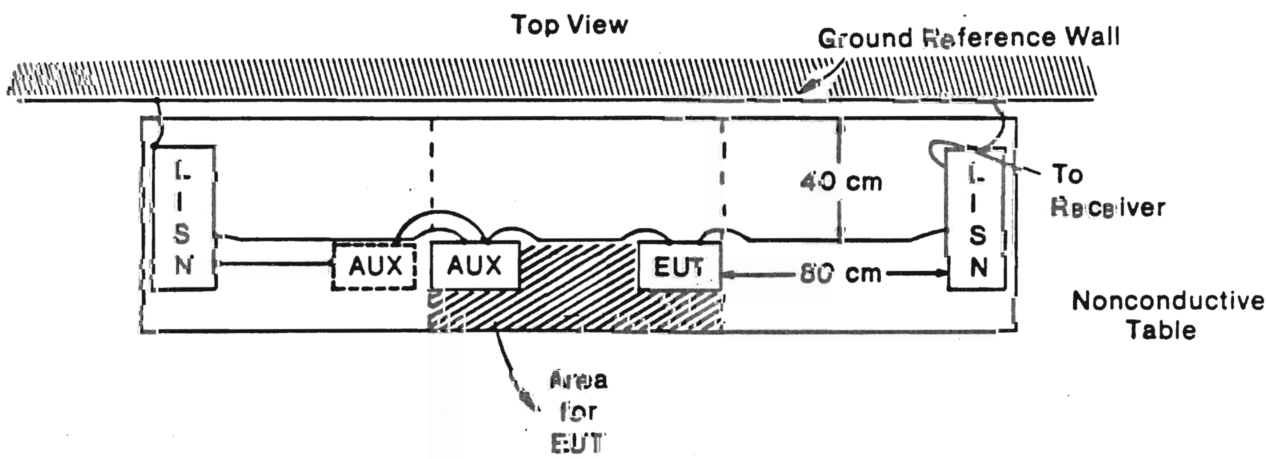




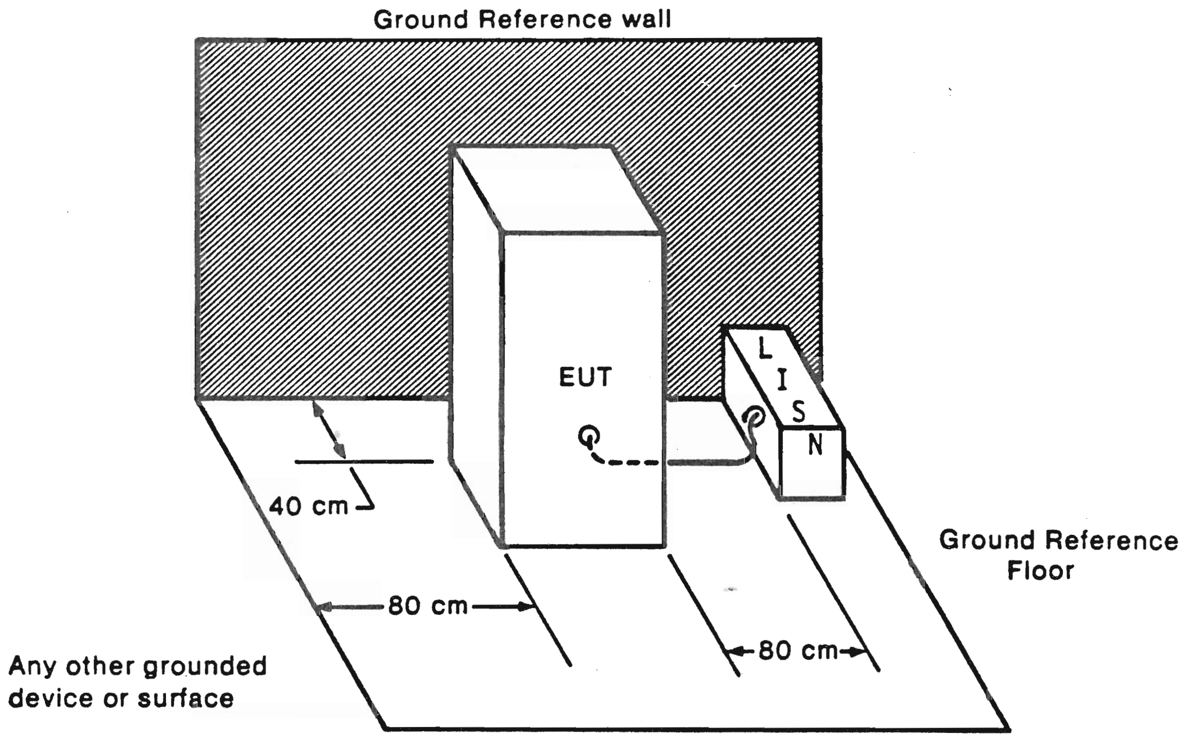
Impedance Frequency Characteristic Of LISN (10 kHz-30 MHz)



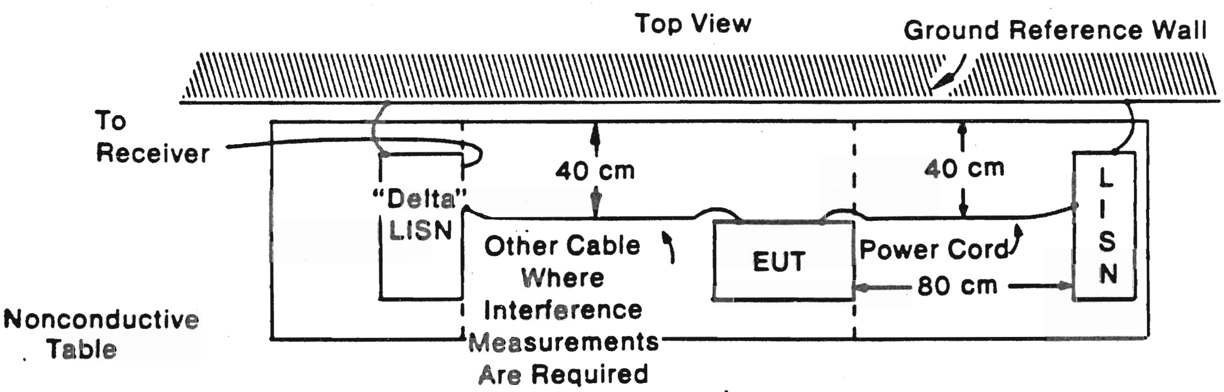
Conducted Interference Typical EUT Arrangement for Table Mounted Product



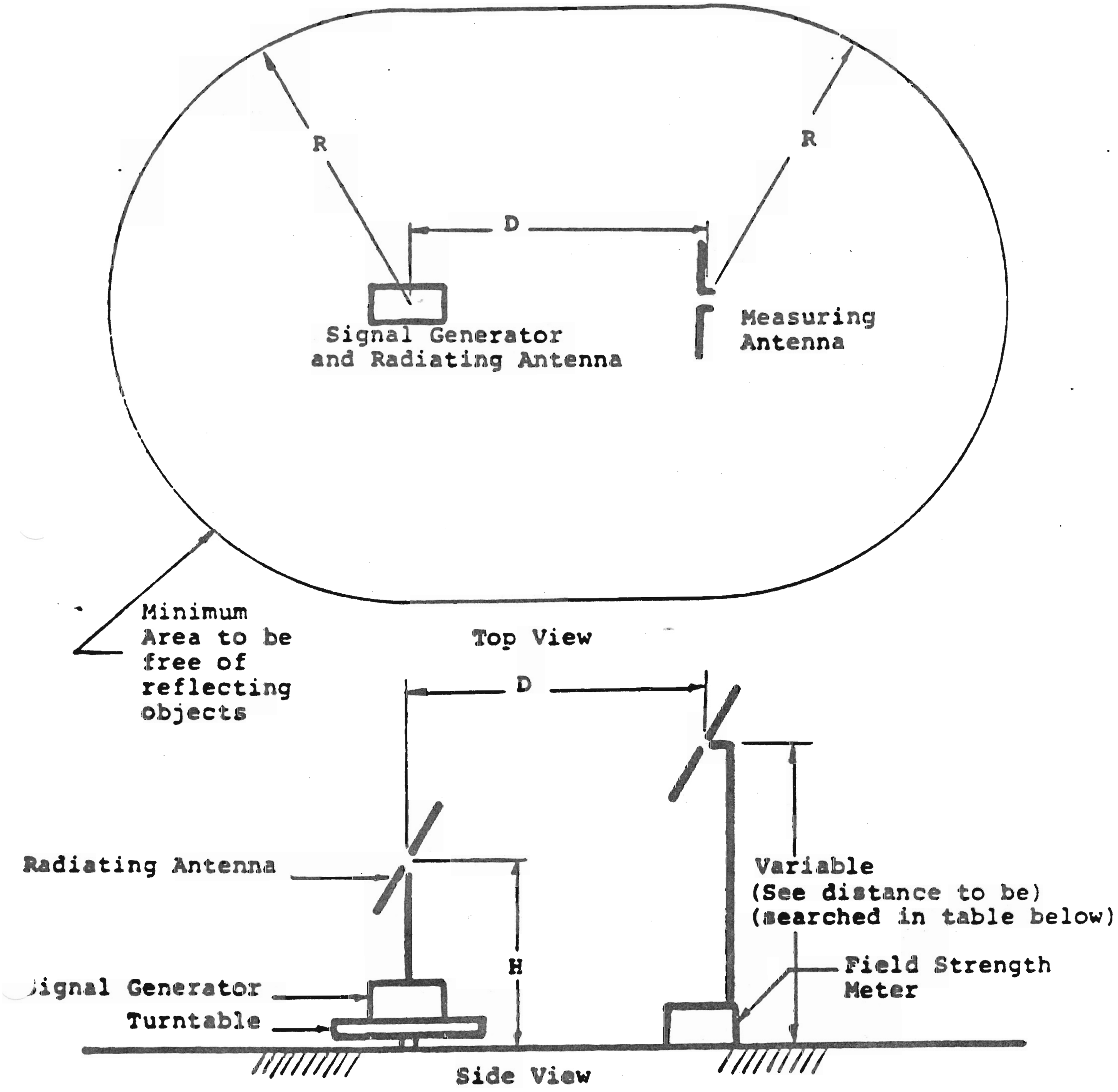
Conducted Interference Typical EUT Arrangement Multi-Product Systems



Conducted Interference Typical EUT Arrangement for Single Floor Mounted Product



Conducted Interference Typical EUT Arrangement Showing "Delta" LISN Placement

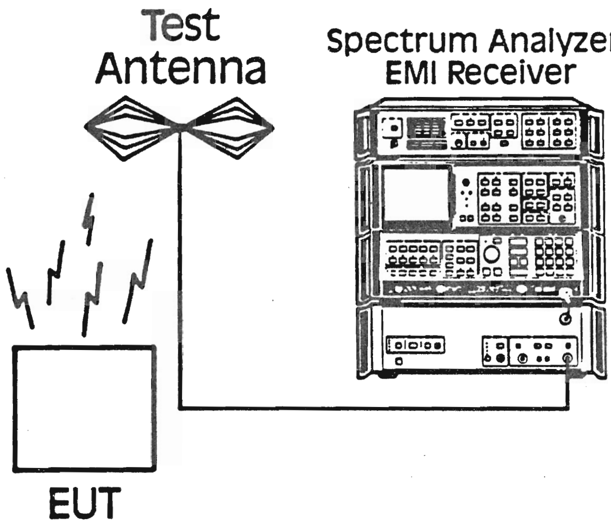


for D = 3m,	R= 3m,	H = 2m,	Search 1-4 meters.
for D = 30m,	R= 50m	H = 5m	Search 2-7 meters.

FIGURE 1. Equipment Arrangement
for Measuring Site Attenuation
of a Radiation Test Site.

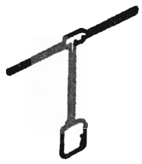
FCC-J. ZOULEK
IE³CS, 21MAY80

CISPR RADIATED TEST INSTRUMENTATION

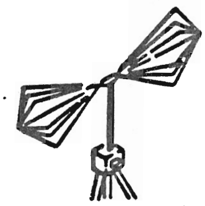


A VARIETY OF ANTENNAS ARE USED FOR CISPR RADIATED TESTS

Tuned, Broadband Dipoles
(25-1000 MHz)



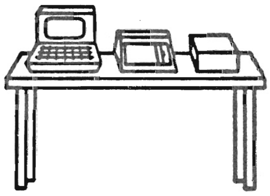
Biconical
(20-300 MHz)



Log Periodic
(200 MHz-10 GHz)

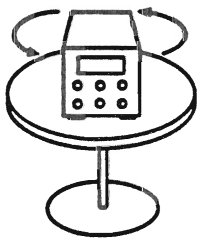
Magnetic Loop
(20 Hz-35 MHz)

CISPR-BASED RADIATED TEST PROCEDURE EMPHASIZES MEASURING THE WORST CASE

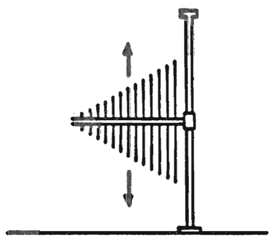


Arrange EUT To Simulate Worst Case Probable Use

Exercise EUT



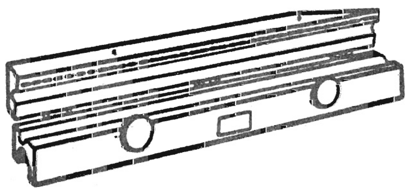
Rotate EUT

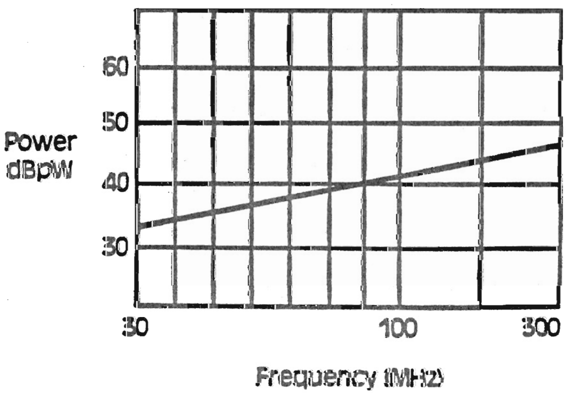


Vary Antenna Height
Use Horizontal And Vertical Polarization

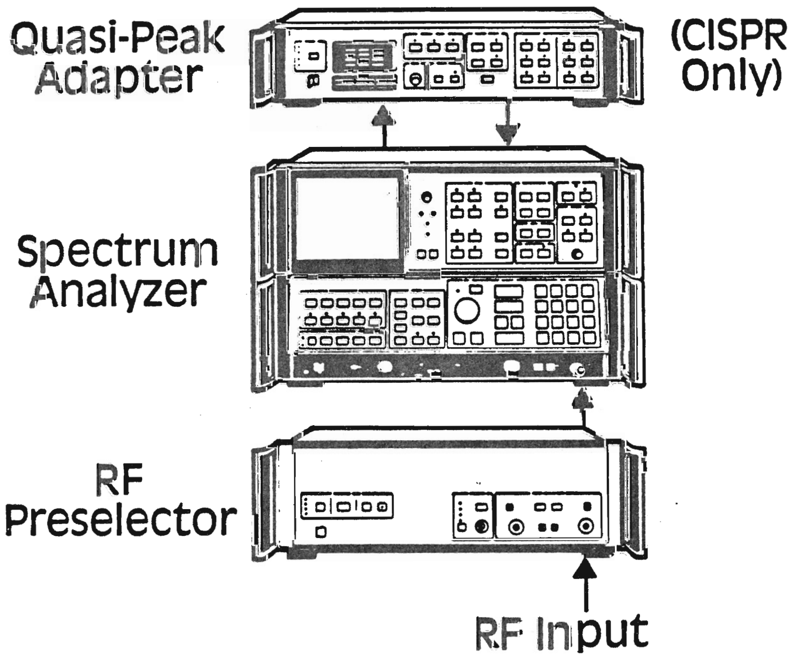
- Distance: 3-30 m
- Antenna Height: 1-4 m (3-10 m Distance)
  2-6 m (> 10-30 m Distance)

THE FTZ GENERAL LICENSE FOR ISM EQUIPMENT REQUIRES NOISE POWER MEASUREMENTS USING AN ABSORBING CLAMP

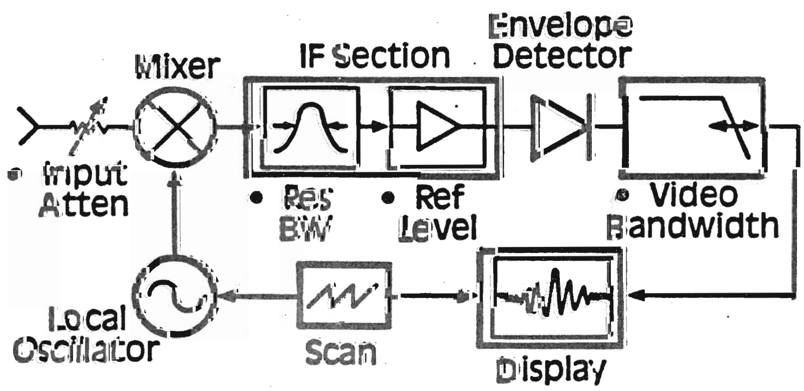




EMI RCVR BLOCK DIAGRAM

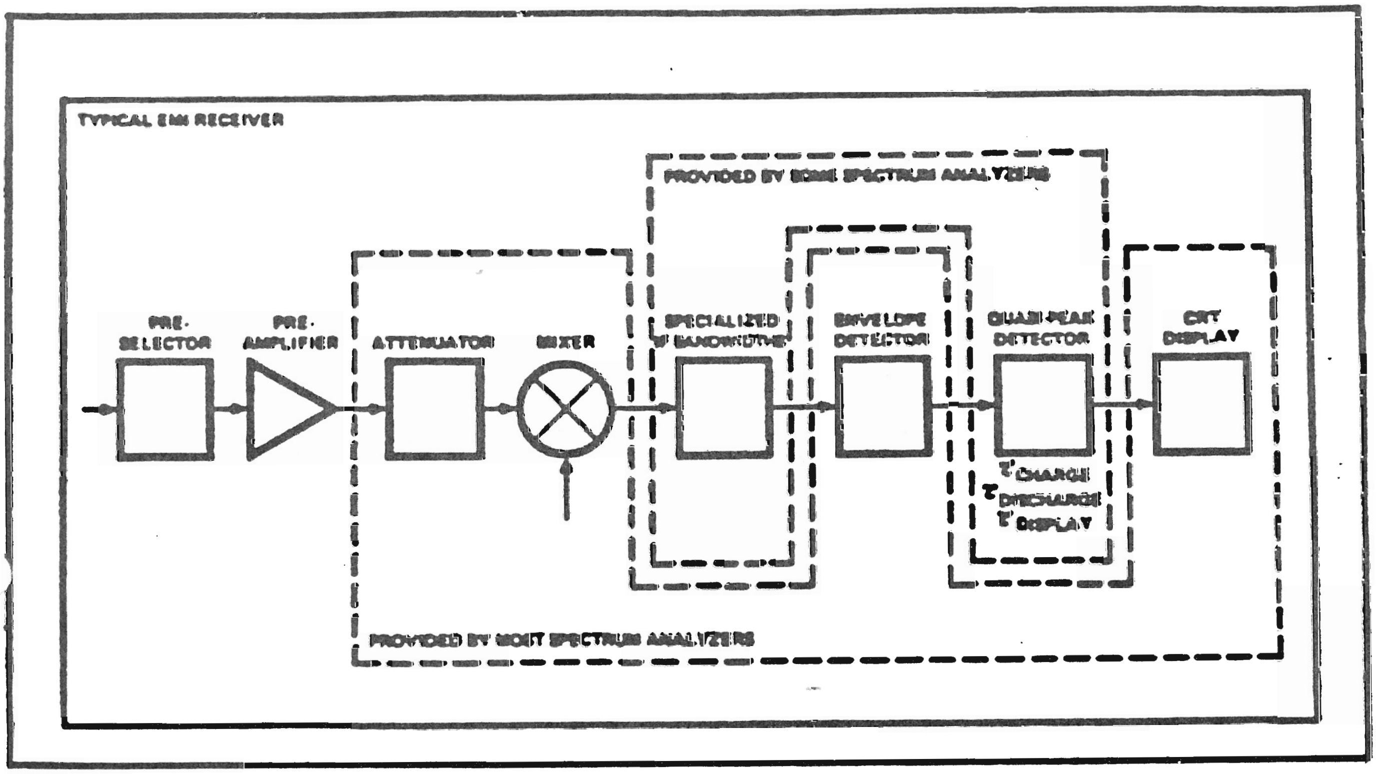


SPECTRUM ANALYZER BLOCK DIAGRAM



- CF
- Span
- Sweeptime

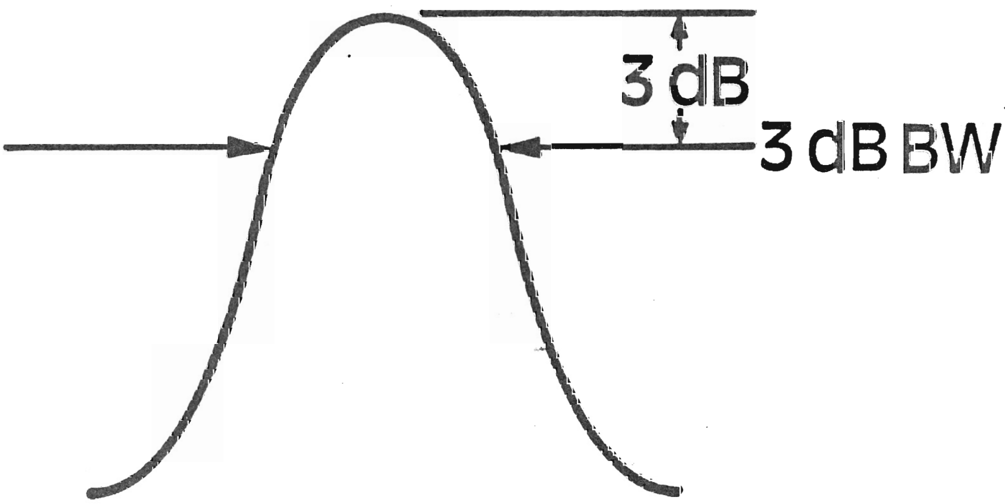
Comparison of a Spectrum Analyzer and an EMI Receiver



THE RESOLUTION BANDWIDTH FILTER DETERMINES:

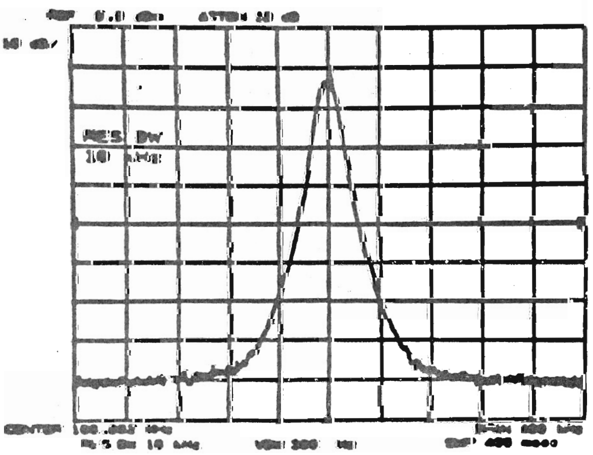
- **RESOLUTION OF ADJACENT SIGNALS** (SELECTIVITY)
- **SPECTRUM ANALYZER SWEEPTIME**
- **SIGNAL TYPE** (BROADBAND OR NARROWBAND)
- **SPECTRUM ANALYZER NOISE LEVEL** (SENSITIVITY)

RESOLUTION OF TWO EQUAL AMPLITUDE SIGNALS IS DETERMINED BY THE IF FILTER 3 dB BANDWIDTH

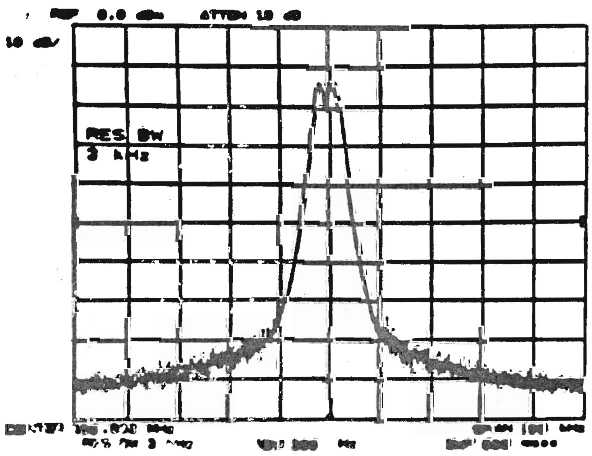


Equal Amplitude Signals Spaced

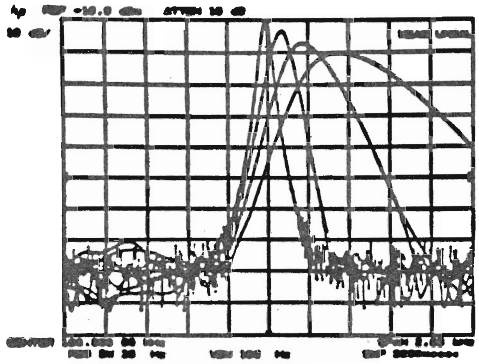
< 3 dB BW



≥ 3 dB BW



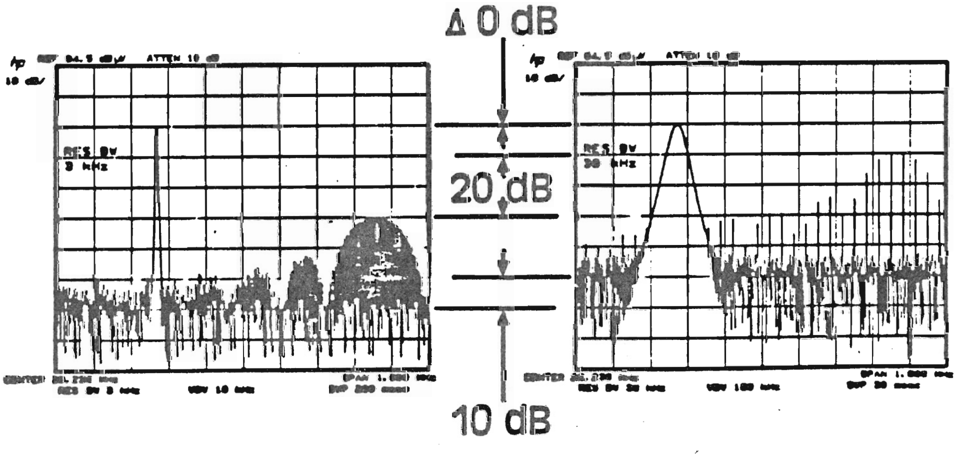
RESOLUTION BANDWIDTH IS ONE FACTOR WHICH DETERMINES MEASUREMENT TIME



Penalty For Sweeping Too Fast
Is An Uncalibrated Display

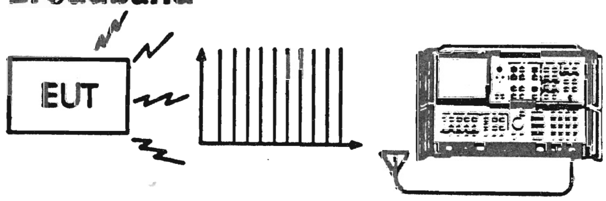
$$\text{Total Sweeptime} \propto \frac{\text{Frequency Span}}{(\text{Bandwidth})^2}$$

THE EFFECT OF RESOLUTION BANDWIDTH ON DIFFERENT TYPES OF SIGNALS

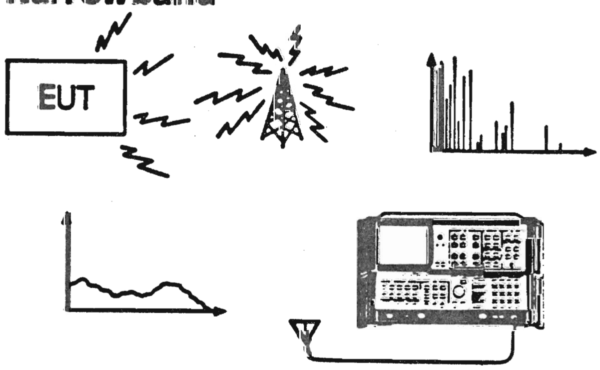


BROADBAND AND NARROWBAND EMISSIONS CAN CAUSE OVERLOAD

Broadband



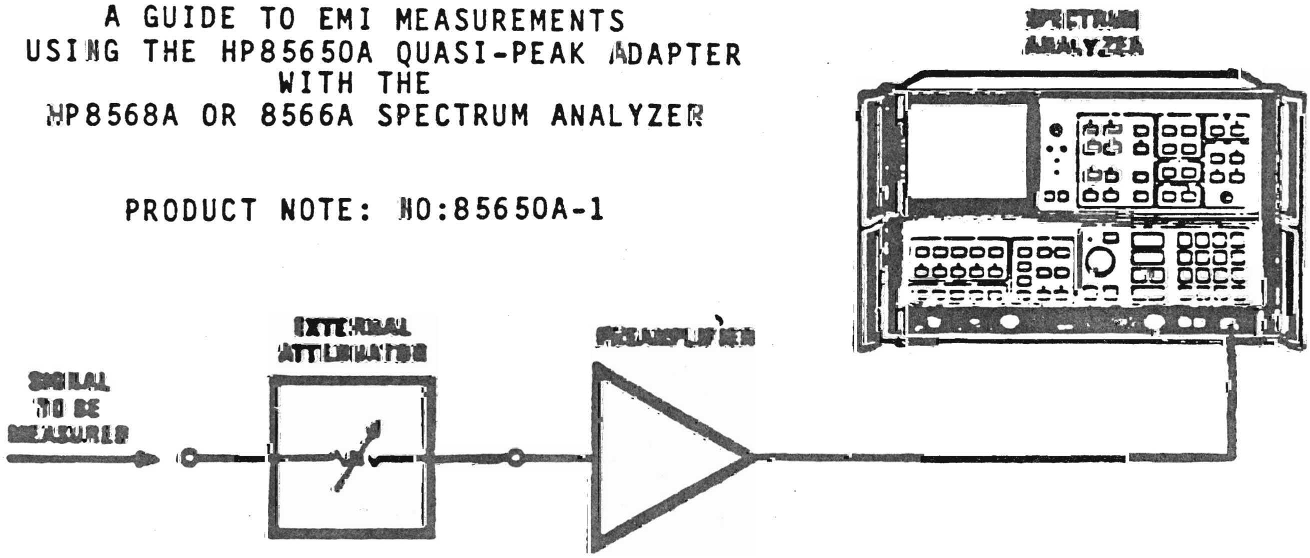
Narrowband



Setup for Overload Test

A GUIDE TO EMI MEASUREMENTS
USING THE HP85650A QUASI-PEAK ADAPTER
WITH THE
HP8568A OR 8566A SPECTRUM ANALYZER

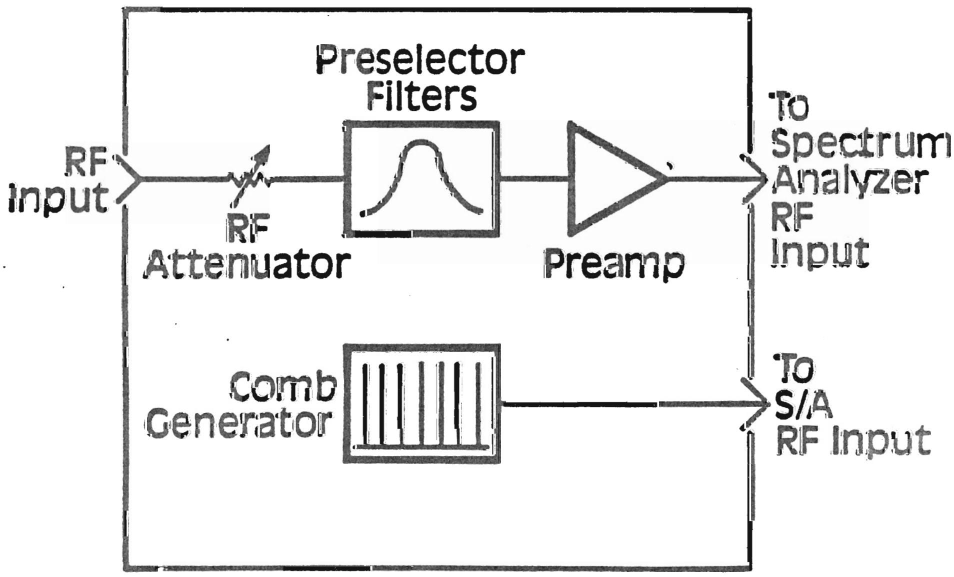
PRODUCT NOTE: NO:85650A-1



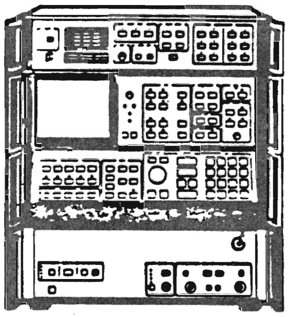
EMI MEASUREMENTS CHALLENGE THE PERFORMANCE OF SPECTRUM ANALYZERS

- OVERLOAD
- SENSITIVITY
- AMPLITUDE ACCURACY

RF PRESELECTOR BLOCK DIAGRAM

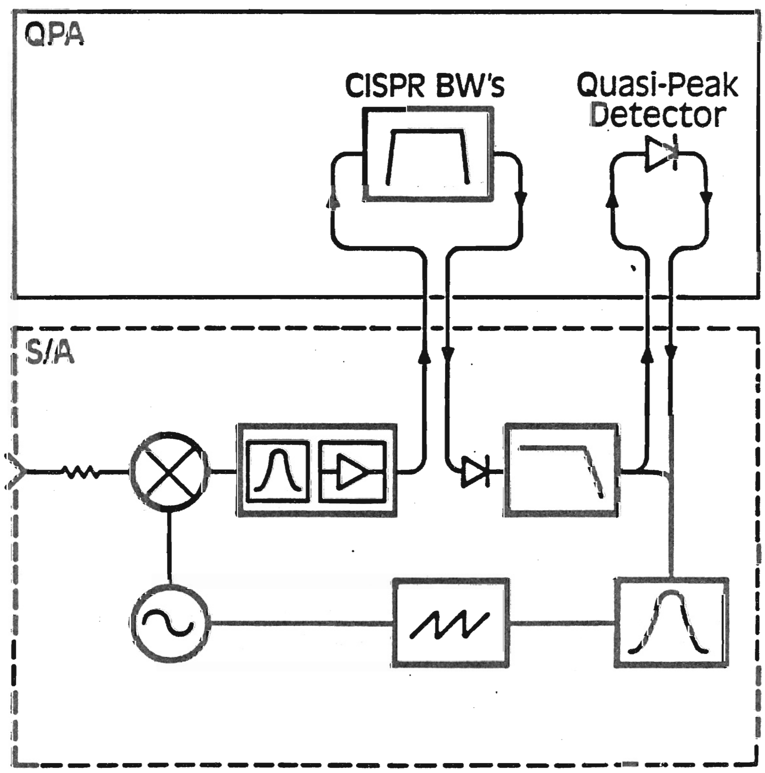


THE QUASI-PEAK ADAPTER PROVIDES REQUIRED CISPR FEATURES



- CISPR BANDWIDTHS
- QUASI-PEAK DETECTOR
- SPEAKERS
- SWITCHES

QUASI-PEAK ADAPTER BLOCK DIAGRAM



THE QUASI-PEAK ADAPTER PROVIDES CISPR SPECIFIED BANDWIDTHS

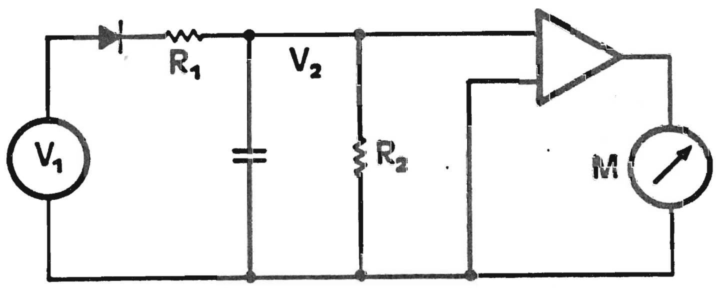
FREQ. BAND	SA RES BW	QPA BW
10-150 kHz	3 kHz	200 Hz
.15-30 MHz	100 kHz	9 kHz
.03-1 GHz	1 MHz	120 kHz

THE QUASI-PEAK ADAPTER ADDS QUASI-PEAK DETECTION CAPABILITY TO THE SPECTRUM ANALYZER/ EMI RECEIVER

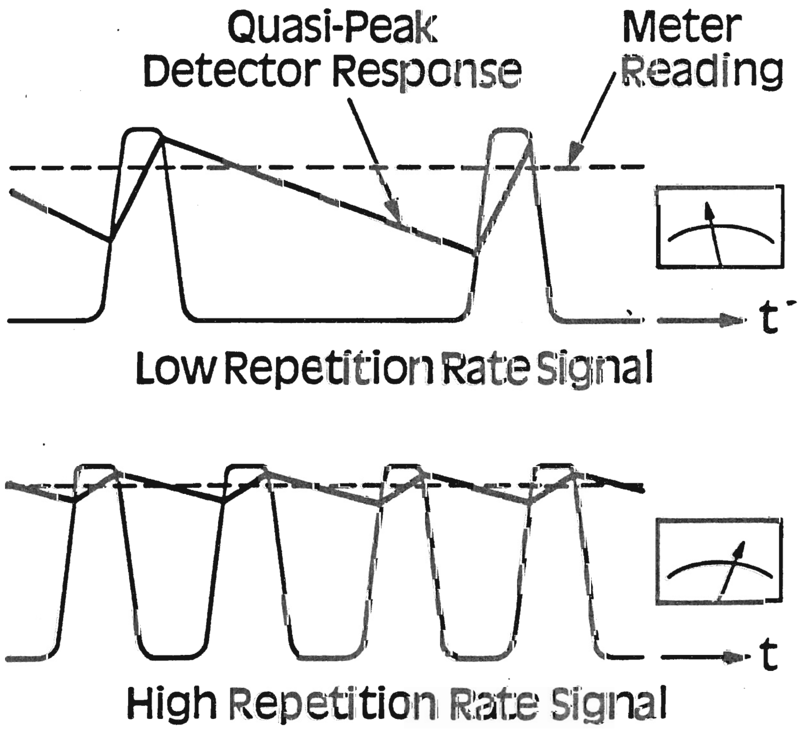
	CISPR	MIL-STD
Peak*	X	X
Average*	X	X
Quasi-Peak	X	

*Provided by Spectrum Analyzer

QUASI-PEAK DETECTION REQUIRES CISPR BANDWIDTHS, LINEAR DISPLAY, AND ADEQUATE SWEEPTIMES



QUASI-PEAK DETECTOR OUTPUT VARIES WITH IMPULSE RATE



- Detector and Meter Movement Time Constants Are Specified
- Quasi-Peak Value ≤ Peak Value

CISPR-BASED MEASUREMENT PROCEDURES

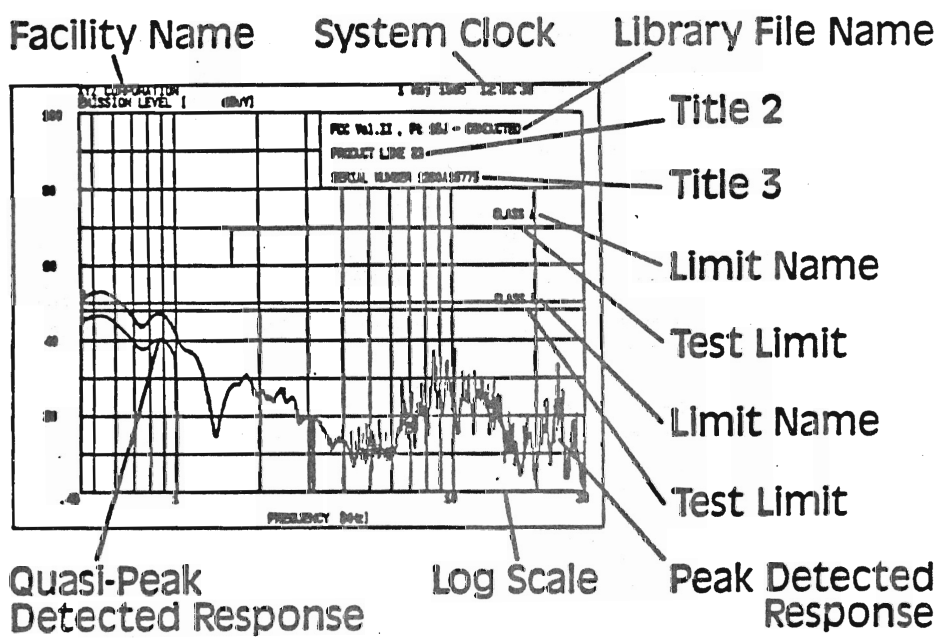
General

- Conditions Must Assure Valid, Repeatable Results
- Radio Noise Meters or Spectrum Analyzers
- Peak or Quasi-Peak Detection
- Bandwidths Specified
- EUT Configured and Exercised for Maximum Response

Conducted Tests

- Shielded Enclosures
- LISN

FULLY DOCUMENTED PLOTS . . .



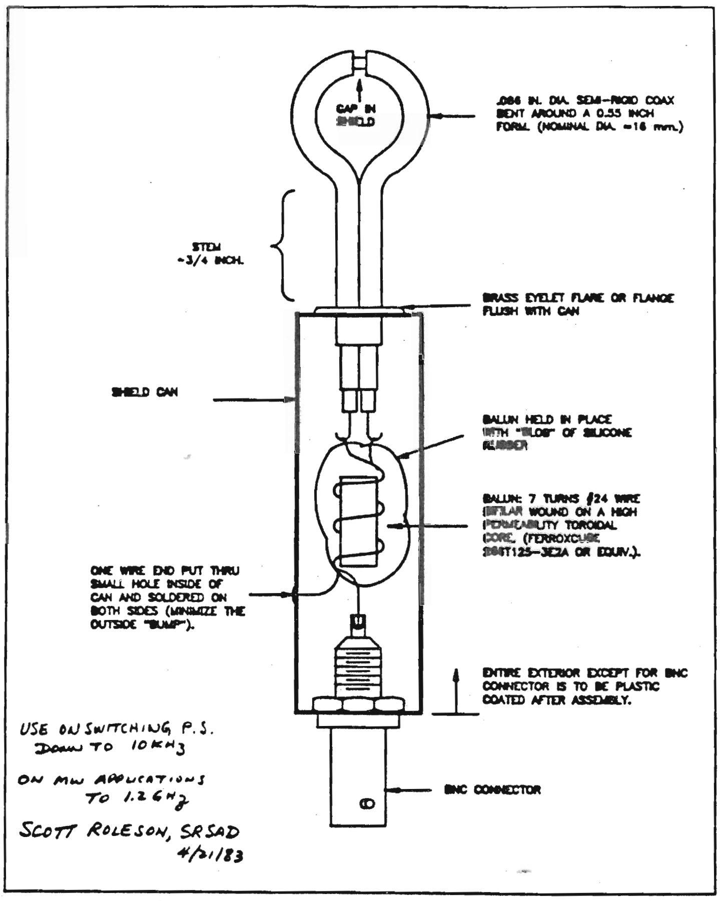
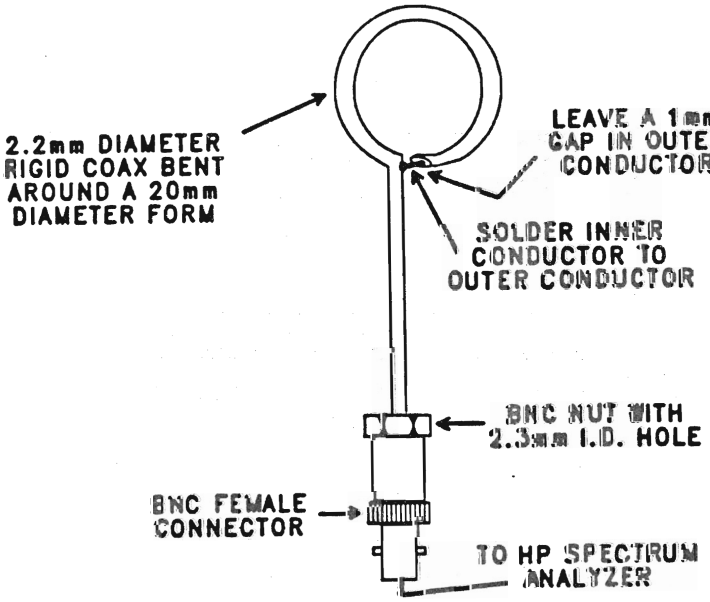


FIGURE 4. A WIDEBAND, VERY SMALL LOOP ANTENNA SUCH AS THIS IS AN EFFECTIVE MAGNETIC FIELD PROBE.

A SIMPLE WIDE-BAND LOOP PROBE



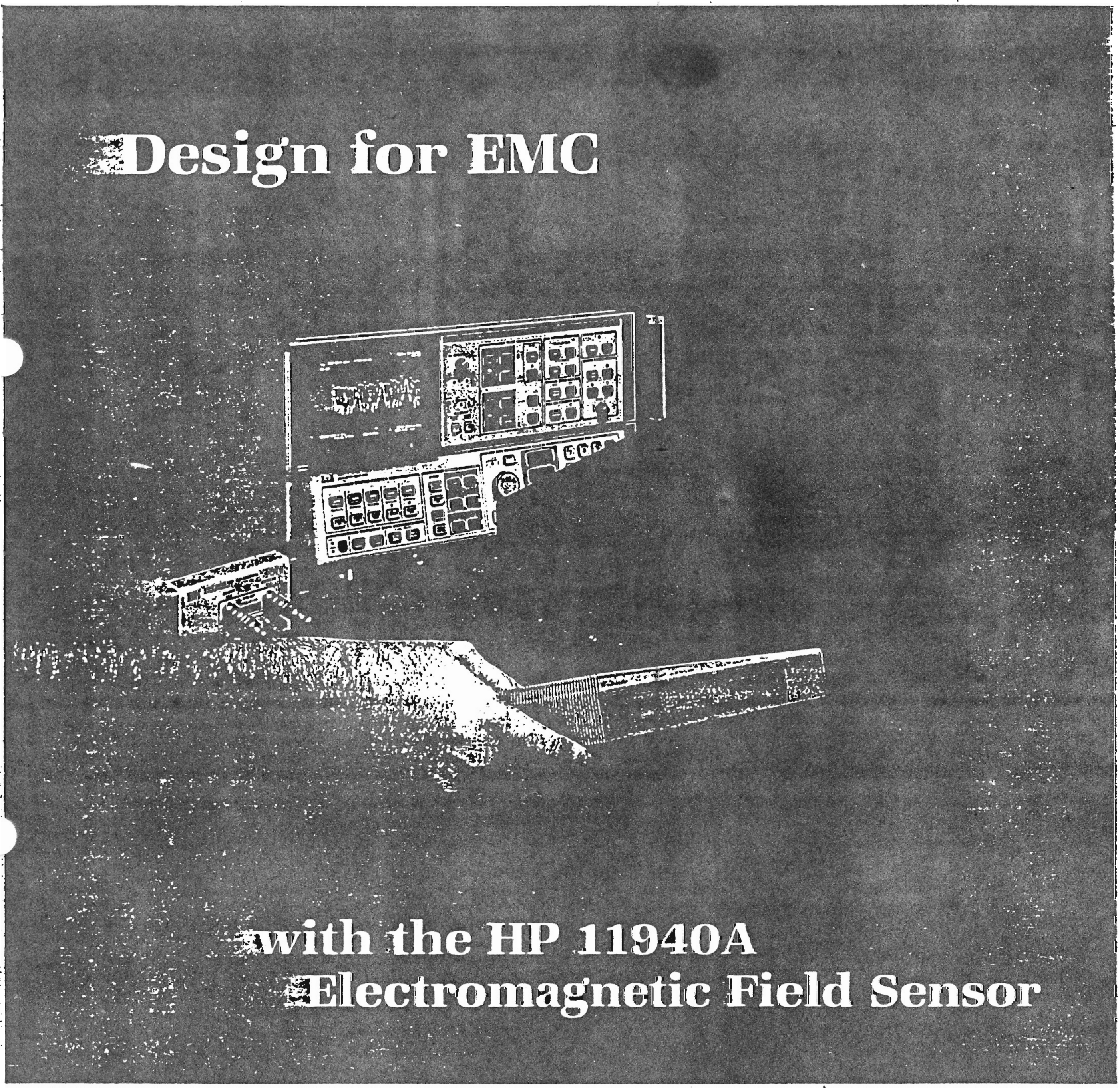
HEWLETT PACKARD

CLOSE-FIELD PROBE

30 MHz to 1 GHz

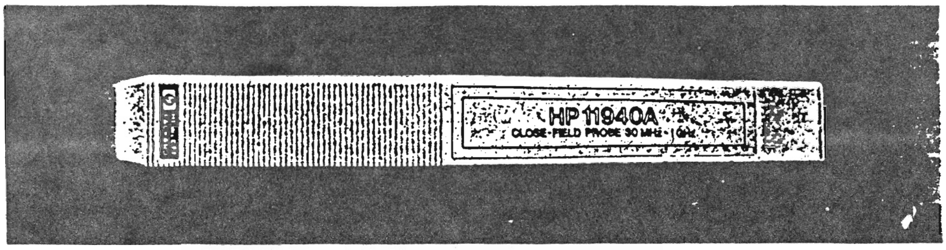
model
HP 11940A

TECHNICAL DATA 1 DEC 85



The HP 11940A Close-Field Probe is a small, hand-held, electromagnetic-field sensor developed for use with a spectrum analyzer in electromagnetic interference (EMI) diagnostic and troubleshooting applications. Unlike a simple magnetic-loop sensor, the Close-Field Probe gives you repeatable, absolute magnetic-field measurements over a wide 30 MHz to 1 GHz frequency range. Especially designed to measure radiation from surface currents, slots, and cables, the HP 11940A is an ideal tool for diagnostic testing of printed circuit boards, cabling, and shielded enclosures. Its unique ability to provide calibrated absolute-amplitude information lets you accurately measure the magnetic-field strength of emissions. When attached to a source, the probe will generate a localized magnetic field for susceptibility testing.

How Does the Close-Field Probe Work?



The Close-Field Probe's dual-loop configuration and balun structure rejects signals due to direct and stray electric-field coupling. This stray electric-field coupling is often a major source of measurement error. The electric-field rejection provided by the HP 11940A, however, significantly reduces this error, allowing you to make repeatable measurements independent of cable layout, measurement-equipment orientation, and ambient environment.

Use the probe in conjunction with a variety of spectrum analyzers and preamplifiers to measure the frequency and absolute amplitude of problem emissions. This gives you an efficient way to track down the emission sources. Because the Close-Field Probe is a small, lightweight, passive device, it maneuvers easily around enclosures or cabling with minimal disturbance of the field. The tip is held very close to potential radiating points, which enables you to accurately locate emission "hot spots." Use the HP 8447D Preamplifier with the HP 11940A Close-Field Probe to isolate sources with amplitudes below MIL-STD 461A/B emission levels.

Who Uses the Close-Field Probe?

Circuit and mechanical designers will find that, as a diagnostic tool, the HP 11940A Close-Field Probe expands the utility of the spectrum analyzer.

Circuit Designer

The Close-Field Probe lets you optimize new product designs to reduce radiation early in the design cycle. Use the probe to help assure circuit compatibility within your design and between system components. Proper modeling of your radiation sources allows you to use data from this sensor to estimate far-field emission levels.

~~As a source of magnetic~~ fields, the Close-Field Probe can be used in localized susceptibility testing. For this application, a known signal fed into the HP 11940A creates a magnetic field at the tip of the device. For broadband susceptibility testing, use the probe with a swept or tracking source such as the HP 8444A Option 059 Tracking Generator.

Mechanical Designer

You can evaluate and compare the relative shielding effectiveness of various enclosures and shielded structures using the Close-Field Probe. This application teams the HP 11940A with a spectrum analyzer and a tracking generator. The tracking generator output signal radiates from any antenna placed inside the enclosure-under-test, while the probe and spectrum analyzer provide frequency and relative amplitude information.

The HP 11940A Close-Field Probe provides the electromagnetic compliance (EMC) test engineer with a valuable tool for diagnosing radiation and susceptibility problems. This makes the goal of electromagnetic compatibility easier to achieve.

HP 11940A Characteristics

Antenna Factor:	Calibrated to within ±2 dB in a 377 ohm field impedance. See Figure 1 for typical antenna factor data.
VSWR:	<3:1, typically
Connector:	SMA, replaceable barrel
Maximum Input Power:	0.5 Watts
Temperature Range:	Typical variation over 0°C - +40°C, <±1 dB
Dielectric Breakdown:	1 kV, typically

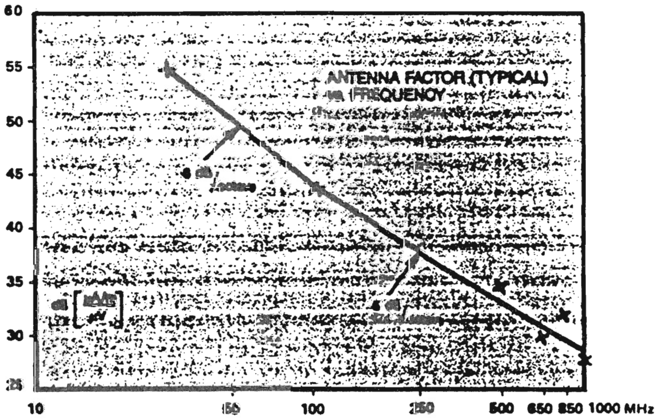


Figure 1. The antenna-factor units used in this chart (dB (µA/m/µV)) should be added to the measured voltage in dBµV on the spectrum analyzer to give magnetic-field strength in dB (µA/m).

The Close-Field Probe is supplied with a calibration chart giving output voltage versus magnetic field strength at five selected frequencies.

Ordering Information

HP 11940A **Close-Field Probe**	$ 500.
Option 001 **Rotary Joint** (available June 1986)	375.
Option 002 **RG223 Cable** (shielded cable) 2m, with SMA connectors	83.
Spectrum Analyzers:	
HP 8567A **RF Spectrum Analyzer** (10 kHz - 1.5 GHz)	27,000.
HP 8568B **RF Spectrum Analyzer** (100 Hz - 1.5 GHz)	34,600.
HP 8566B **Microwave Spectrum Analyzer** (100 Hz - 22 GHz)	55,000.

Accessories:

HP 8447D Preamplifier (100 kHz - 1.3 GHz)	$ 1,100.
HP 8444A Option 059 Tracking Generator (100 MHz - 1.5 GHz)	4,760.
HP 8656B Signal Generator (0.1 - 990 MHz)	6,500.

For more information, call your local HP sales office listed in the telephone directory white pages. Ask for the Electronic Instruments Department. Or write to Hewlett-Packard: **U.S.A.** — P.O. Box 10301, Palo Alto, CA 94303-0890. **Europe** — P.O. Box 999, 1180 AZ Amstelveen, the Netherlands. **Canada** — 6877 Goreway Drive, Mississauga, L4V 1M8, Ontario. **Japan** — Yokogawa-Hewlett-Packard Ltd., 3-29-21, Takaido-Higashi, Suginami-ku, Tokyo 168. Elsewhere in the world, write to Hewlett-Packard Intercontinental, 3495 Deer Creek Road, Palo Alto, CA 94304.

PRICES AND DATA SUBJECT TO CHANGE

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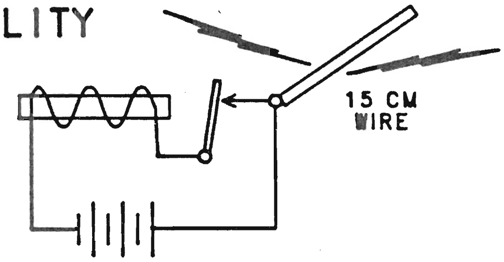
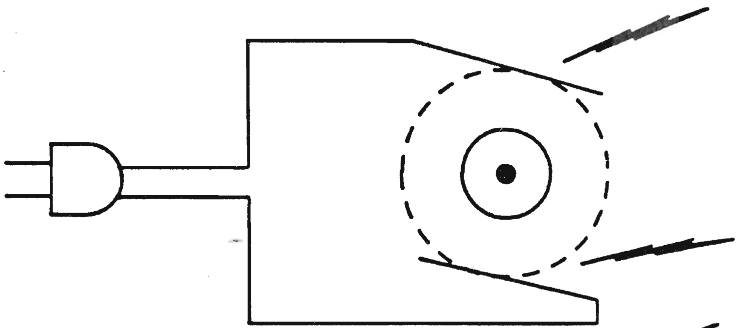
SOURCES FOR TESTING SUSCEPTIBILITY

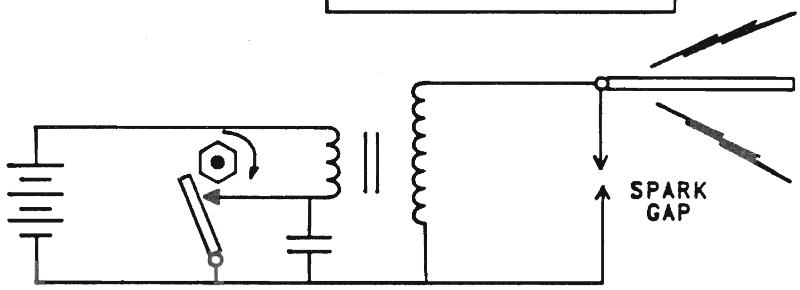
1. CHATTERING RELAY WITH 15 CM ANTENNA



2. ELECTRIC APPLIANCE WITH BRUSH TYPE MOTOR, ESPECIALLY GOOD FOR CONDUCTED EMI (i.e. SHAVER, ELECTRIC DRILL)

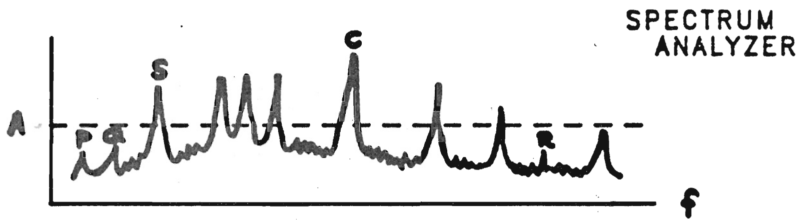


3. IGNITION COIL



SUMMARY
GETTING STARTED - SOLVING AN EMI PROBLEM

MEASURE:

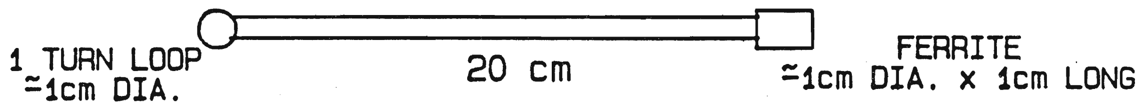


ANALYZE:

WHICH ARE INTENTIONAL (USEFUL) SIGNALS? S,C,P,Q,R
WHICH ARE NON-INTENTIONAL (NOT USEFUL) SIGNALS?
- ARE SOME NON-COHERENT (NOISE, BB) SIGNALS?

FIND/IDENTIFY:

TURN SOURCES ON/OFF AND WATCH SPECTRUM ANALYZER
TURN ON/OFF/SHORT MIXERS, BUFFER, DIVIDERS, CLOCKS, FLIP-FLOPS, GATES, ETC.
PROBE NEAR COMPONENTS WITH EMI USING LOOPS, FERRITE;



SUMMARY STEPS

1. ELIMINATE
2. ISOLATE
3. REORIENT
4. SHIELD
5. FILTER
6. GROUND
7. BALANCE/CANCEL
8. IMPEDANCE CONTROL
9. CABLE DESIGN
10. MINIMIZE LOOPS
11. PC TRACE REDESIGN
12. MINIMIZE/MOVE RESONANCE
13. ELIMINATE NON-LINEAR DEVICES

E M I REDUCTION CHECKLIST

REDUCING NOISE AT THE SOURCE

- ___ MINUMIZE LOOPS CONTAINING PULSE CURRENTS
- ___ SHIELD NOISE SOURCES AT THE MODULE LEVEL
- ___ FILTER LEADS LEAVING A NOISY MODULE
- ___ USE TWISTED WIRE PAIRS TO CANCEL NOISE
- ___ USE SHIELDED WIRES WHERE NECESSARY
- ___ USE PULSES WITH SLOWEST POSSIBLE RISE TIME

REDUCING NOISE COUPLING

- ___ ROUTE LEADS WITH LOW LEVEL SIGNALS NEAREST CHASSIS
- ___ USE TWISTED WIRE PAIRS
- ___ USE COAX CABLES AT THE HIGHER FREQUENCIES & GROUND BOTH ENDS
- ___ USE COAX CABLES AT LOWER FREQUENCIES WITH ONE END GROUNDED
- ___ USE SEPARATE GROUNDS FOR HIGH AND LOW LEVEL SIGNALS
- ___ USE SEPARATE PINS ON CONNECTORS FOR SIGNAL GROUNDS
- ___ ON RIBBON CABLES, PLACE NOISY SIGNAL ON EDGE NEXT TO A GROUND

REDUCING GROUND COUPLING

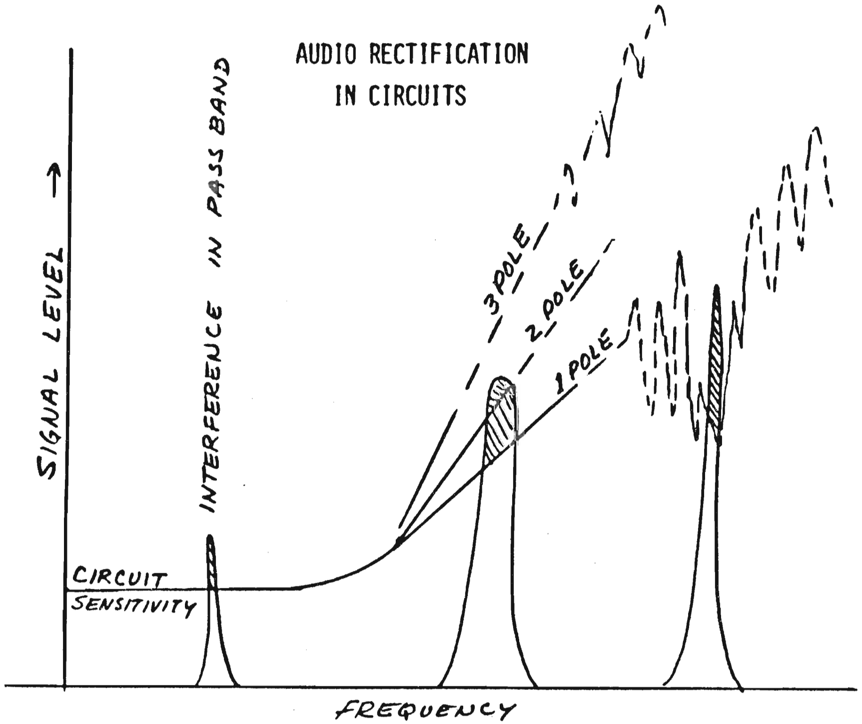
- ___ MAKE GROUND LEADS SHORT AS POSSIBLE
- ___ SEPARATE NOISY AND QUIET GROUNDS
- ___ AVOID GROUND LOOPS
- ___ INSTALL CIRCUIT GROUNDS SEPARATE FROM CHASSIS GROUNDS
- ___ USE STAR LOCK WASHERS TO BREAK PAINT FOR GROUND ON CHASSIS
- ___ FOR HIGH FREQUENCIES, USE A SINGLE GROUND
- ___ MOUNT COMPONENTS SECURELY TO PREVENT ACCIDENTAL GROUNDS
- ___ USE BALANCED CIRCUITS WHERE NECESSARY TO AVOID GROUND LOOPS

OTHER REDUCTIONS

- ___ INSTALL LOW IMPEDANCE LINES FOR POWER LINES
- ___ KEEP SENSITIVE LEADS SHORT
- ___ PLACE SENSITIVE CIRCUITS INSIDE A SHIELDED ENCLOSURE
- ___ FILTER LEADS TO SENSITIVE CIRCUITS IN AN ENCLOSURE
- ___ LEADS BEYOND THE CABLE SHIELD SHOULD BE SHORT AS PRACTICAL

REDUCING NOISE TO A RECEIVER OR SENSITIVE CIRCUITS

- ___ LIMIT BANDWIDTH ONLY TO THAT NECESSARY
- ___ SEPARATE SENSITIVE AND NOISY CIRCUITS
- ___ DECOUPLE THE POWER SOURCES
- ___ USE A SMALL BYPASS CAPACITOR IN PARALLEL WITH ELECTROLYTICS
- ___ CONNECT CASE OR OUTSIDE FOIL END OF CAPACITORS TO GROUND
- ___ IF NECESSARY, USE SHIELDED ENCLOSURE
- ___ USE FREQUENCY SELECTIVE FILTERS WHERE PRACTICAL



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THE CENTER FOR PROFESSIONAL ADVANCEMENT (HENRY W. OTT)
P.O. BOX H
EAST BRUNSWICK, NEW JERSEY 08816, U.S.A.

EMC/EMI PUBLICATIONS:

EMI CONTROL METHODOLOGY & PROCEDURES (DESIGN SYNTHESIS)
DONALD R.J. WHITE (SEE ABOVE FOR ADDRESS)

NOISE REDUCTION TECHNIQUES IN ELECTRONIC SYSTEMS
BY HENRY W. OTT, (JOHN WILEY & SONS, NEW YORK, USA)

IEEE GROUP ON ELECTROMAGNETIC COMPATIBILITY
IEEE SERVICE CENTER, 445 HOES LAND, PISCATHAWAY, N.J. 08854, USA

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DEFENSE TECHNICAL INFORMATION CENTER
DEFENSE LOGISTICS AGENCY
CAMERON STATION, ALEXANDRIA, VA 22314

EMC DESIGN GUIDE, NAVAIR AD 1115, JULY 1980 REV.
FOR AVIONICS AND RELATED GROUND SUPPORT EQUIPMENT
COMMANDER, NAVAL SURFACE WEAPONS CENTER, DAHLGREN LABORATORY
ATTN: DF-52, DAHLGREN, VA 22448

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